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Drought Characteristics Assessment in Europe over the Past 50 Years

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Abstract

The questions of scale, limit, and areal extent are central points for any drought assessment effort. Drought indices, such as the Standardized Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index (SPEI), are assisting to demarcate drought characteristics and spatial extent. The current approach utilizes the E-OBS gridded dataset's hydro-climatic parameters (precipitation, minimum and maximum temperature) for applying SPI and SPEI on a Pan-European scale for a detail drought assessment during the 1969–2018 period. The two indices are estimated for the 6 and 12-month scales. In this effort, drought is defined as an event that has index value less than minus 1.5 for at least three consecutive months. Based on this, drought characteristics (frequency, duration, and severity) are derived. The results are displayed in 5-year windows and they are also assessed against independently recorded droughts as occurred. Overall, it may be reported that there has been little change in drought characteristics over the past 50 years in Europe. Furthermore, given the variety of climatic locales on a continental level, the 6 and 12-month time scales for both indices may offer an improvement on drought critical areas identification, threshold definitions, and comparability.

Keywords Drought · Drought characteristics · Drought index · Standardized precipitation index · SPI · SPEI

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1 Introduction

Drought is a reoccurring natural hazard, initiated by precipitation shortfall when compared to average climatic conditions and amplified in cases of concurrent heatwaves, which can have harsh and long-lasting impacts on both physical and human systems (Vlachos 1982; Grigg and Vlachos 1993; Van Lanen et al. 2013; Grigg 2014; Karavitis et al. 2014). It is a complicated process characterized by precipitation deficits, severe runoff problems, increased temperatures, and of course, it affects all societal sectors, including water supply, energy, food production, and it may jeopardize both local and global economies. There is no single universal definition that can explain and be applied to all types of droughts, making it difficult to accurately determine its beginning and ending points.

Thus, to objectively characterize a system's status regarding drought onset, magnitude, and duration indicators offer a valuable tool in the attempt to portray and convey these dimensions to decision-makers in a comprehensible way and consequently initiate management measures to confront droughts timely and accurately. Many indices illustrate the drought dimensions based on meteorological, water supply and demand information. Some of the ones mostly used are the Standardized Precipitation Index (SPI) (McKee et al. 1993), the Standardized Precipitation-Evapotranspiration Index (SPEI) (Lorenzo-Lacruz et al. 2010), and the Reconnaissance Drought Index (RDI) (Tsakiris et al. 2007). However, no single drought index alone may precisely describe all the phenomenon's attributes, with each index having pros and cons, and none of them being superior overall (Hayes et al. 2002). According to Keyantash and Dracup (2002), SPI was found to be a valuable estimator of drought severity. SPEI seems to be better correlated than the SPI with environmental impacts (Lorenzo-Lacruz et al. (2010); Blauhut et al. (2016). Drought impacts in water resources are often better represented by the SPI rather than by streamflow percentiles (Bachmair et al. 2015). Furthermore, applying multiple drought indicators provides crucial information to monitor and categorize the phenomenon (Oikonomou et al. 2018). Hence, the combination of SPI and SPEI to describe drought conditions in Europe is common in literature and offers a well-tested and dependable approach.

There is a plethora of drought incidents in Europe over the last fifty years, with variable spatial extent, severity, frequency, and duration, as well as impacts. The most recent major drought occurred during the summer of 2018 affecting most of northern Europe, compelling EC to aid impacted farmers (EC 2018). The droughts events with recorded spatial extend exceeding 30% of EU, during the 1969–2018 period, were the ones in 1972–74, 1990–94, 2000, 2003, 2007, 2011, and 2018 (EEA 1999; EEA 2015; Spinoni et al. 2015; Di Liberto 2018). The estimations of the overall economic drought impacts in the EU, excluding social and environmental costs, exceeded 100 billion € (EC 2007). The annual average drought impacts in the 1976–2006 period doubled during the second half (1991–2006) rising to € 6.2 billion/year, with only 1989–1990 costing 1.2 billion € for Greece (Karavitis 1999); whereas the 2003 event cost was 8.7 billion € (EEA 2010). Pertinent literature focusing on EU drought information and climatic variability have identified the Alps mountain range parallel as the natural north-south boundary defining two geographical regions in terms of meteorological, environmental, and geomorphological conditions.

Existing climatic trends undoubtedly affect the severity and intensity of droughts in the twenty-first century. The IPPC's models premises produced scenarios forecasting that by 2100 a significantly greater number of people than nowadays will be exposed to water-related challenges, including droughts (IPCC 2014). If those scenarios are to be realized, millions of lives and considerable economic assets will be at risk. This may deviate from existing patterns, as Sheffield et al. (2012) observed that there has been little change for drought characteristics over the past 60 years. Further on Hanel et al. (2018) presented that recent seasonal droughts over Europe fall within their historical long-term magnitude fluctuations. The extreme drought events during the last 250 years had as onset late summer and early autumn. These droughts were longer, more intense, and spatially more extended than the recent ones (Brázdil et al. 2018). Noone et al. (2017) reported after presenting a 250-year drought catalog of Ireland that the recent years are not representative of the country's drought climatology, and a larger time envelope should be utilized for efficient drought management options. Overall, the drought characteristics depiction is still an open and debated issue which is strongly related to the initial research premises and orientation (Sheffield et al. 2012; Dai 2013; Spinoni et al. 2014; Trenberth et al. 2014; Noone et al. 2017; Spinoni et al. 2017; Stagge et al. 2017).

The scope incorporating also the novelties of this work is to assess and visualize drought frequency, duration, and severity in Europe over the last 50 years (1969–2018). The first novelty was to represent droughts all over Europe using SPI and SPEI for the 6 and 12-month scales, as more appropriate than the 3-month scale used in other efforts. The second was to distinctly portray this representation on a 5-year time step, hence visualizing droughts in detail with ten quinquennia. The third was assessing such efforts against the already described droughts in the literature over the last half-century, an approach not performed in a Pan European scale. It is believed the assessment results would vote towards the validity of the approach as the generated outcomes are methodically compared to existing incidents. Hence, the effort may help water resources managers and stakeholders to accurately mitigate the adverse impacts of drought, as the product of duration and magnitude results in the delineation of drought severity. To accomplish these goals a gridded daily dataset of hydro-climatic variables is utilized to estimate two drought indices (SPI and SPEI) for two time scales (6 and 12-month). In order to quantify drought characteristics over Europe, a reference drought event based on magnitude and duration for both indices is defined. The following sections describe the study area and the datasets used, the developed methodology, and discusses in detail the results following a quinquennium time window. Independent drought characterization efforts in the literature utilized to assess the findings.

2 Methodology

2.1 Study Area and Dataset

Assessing drought conditions and its spatial extent involves difficulties mostly associated with observation data quality, station space density, homogeneity issues, and common record spans. When the site involves several countries the analysis has inherent limitations directly associated with the datasets used. The daily E-OBS gridded dataset covers the area of 25 N–71.5 N × 25 W–45 E in a 0.25-degree regular latitude-longitude grid resolution (Cornes et al. 2018). E-OBS is constructed based on an extensive network of meteorological stations. However, station coverage across the domain is not the same, and there was no homogeneity correction performed to remove biases (Cornes et al. 2018). Despite known limitations, the E-OBS daily gridded dataset is considered as the best available for continental spatial analysis in Europe (Serrano-Notivoli et al. 2019).

The key hydro-climatic E-OBS parameters for drought assessment are the ensemble means of daily minimum and maximum temperature, and daily precipitation. The variables' time record within the spatial domain varies from grid cell to grid cell. For consistency and comparability, it was chosen to include only the grid cells with complete monthly information for the 1969–2018 period. As a result, the study area encompasses most of continental Europe, including Cyprus and the European part of Turkey (Fig. 1a). Iceland, Sicily and southern Calabria (Italy), the southern half of Greece, and most of Eastern European Russia were excluded due to incomplete observation records, while eastern Latvia was not included due to data quality issues.

2.2 Methods

The context of continental or global drought assessment utilizing SPI and/or SPEI is becoming more and more frequent in the literature (Lloyd-Hughes and Saunders 2002; Spinoni et al. 2014; Spinoni et al. 2015; Zarch et al. 2015; Spinoni et al. 2017; Stagge et al. 2017; Oikonomou et al. 2018). Spinoni et al. (2017) reported past drought trends all over Europe on both annual basis (from 1950 to 2012) and seasonal basis (from 1950 to 2015). They

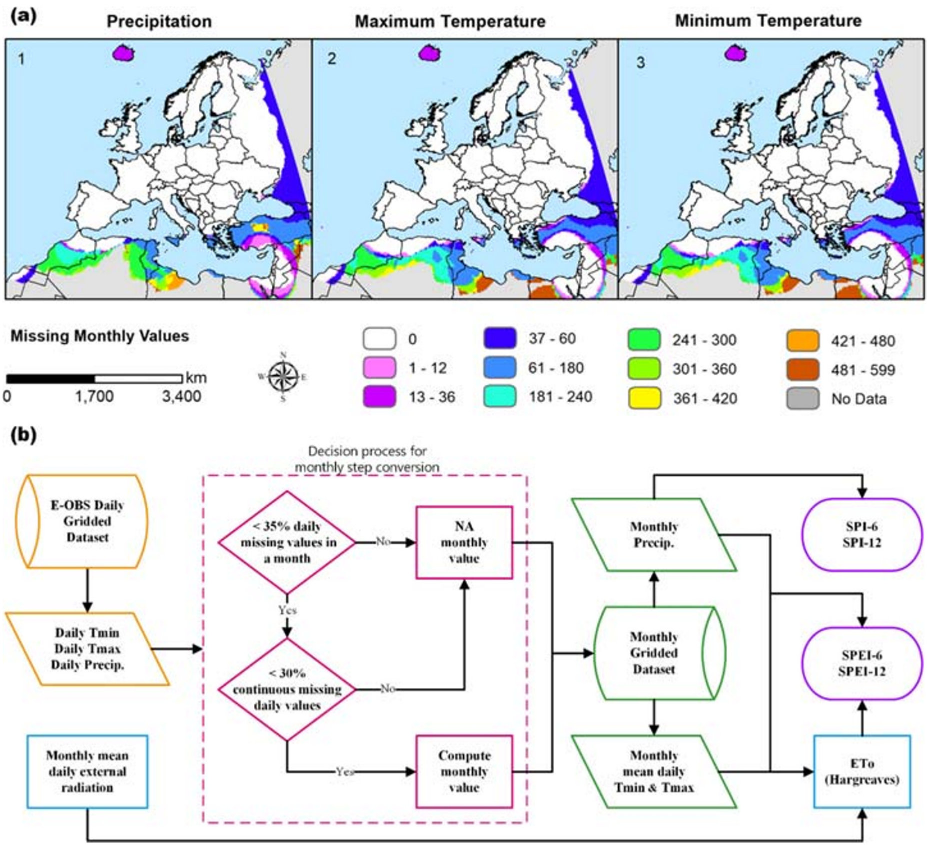

Fig. 1 **a** Spatial domain of E-OBS dataset and the number of precipitation, maximum and minimum temperature missing monthly values for 1969–2018 and (**b**) schematic representation of the process and the data sets utilized at every grid cell for the calculation of SPI and SPEI

selected the 3-month scale for seasonal drought patterns and the 12-month scale for the annual ones for all Europe. Their results from 1950 to 2010, showed drought frequency and severity having decreasing tendencies over northern and parts of Eastern Europe, increasing tendencies over Southern and Western Europe, with Central and some Eastern Europe parts representing the transition zone. However, Wu et al. (2007) pointed out that SPI values with scales up to 12 weeks in arid and semi-arid regions are non-normally distributed. They underlined that short time scale SPI values in such locales should be applied with caution since zero precipitation is a standard of the local climate during a certain annual period and may lead to drought characteristics misinformation. This fact was also pointed out in the Mediterranean region as well as in other semi-arid parts of the world (Oikonomou and Waskom 2018). Southern Europe experiences extended summers with minimal to no precipitation from May to September. This natural climatic characteristic, in terms of drought interpretation, denotes that the manifestation of a drought can be initiated only during the winter months. More explicitly, in an area with 10 mm of a typical summer month precipitation (e.g. Greece with an approximate average 700 mm/yr), an 80% decrease to 2 mm may be depicted by an index as a drought, which is insignificant for the overall annual precipitation budget and at no circumstances may declare a drought per se. Whereas the opposite applies to the central and northern Europe, since precipitation deficit during the rainy summer season will commence a drought. The 6-month scale is resulting in SPI values being normally distributed (Wu et al. 2007). A 6-month SPI may be very effective revealing the precipitation patterns over distinct seasons, indicating medium-term trends and to denote not only meteorological but also agricultural droughts (Karavitis et al. 2012; Karavitis et al. 2014; Oikonomou 2017; Stagge et al. 2017; Tsesmelis et al. 2019b; Oikonomou et al. 2019; Tsesmelis et al. 2019a). Utilizing the SPI with periods 6 and 12-month scale may also display irregularities in water resources and particularly reservoir storage (hydrological droughts) (Tsakiris and Vangelis 2004; Karavitis et al. 2012; Oikonomou 2017; González-Hidalgo et al. 2018). SPI values of 6-months and above time scales seem more appropriate for drought characterization than the 3-month and below for all climatic zones in Europe. Thus, the SPI-6, SPEI-6, SPI-12, and SPEI-12 have been selected for drought characterization.

Figure 1b summarizes the process for the drought indices computation at each grid cell (93,264 cells calculated in total). The first step for the 6 and 12-month SPI and SPEI calculation was the temporal transformation of the daily E-OBS information into monthly. In each grid cell, a monthly value was computed if at least 65% of the daily record was present, and there was no continuous gap of more than 30%. For the SPEI calculation, monthly reference evapotranspiration was computed based on a modification (Droogers and Allen 2002) of the original Hargreaves method with monthly mean daily external radiation estimated based on latitude and month of the year (Hargreaves 1994). The estimation of the drought indices used typical distributions, gamma for SPI (McKee et al. 1993; Lloyd-Hughes and Saunders 2002; Stagge et al. 2015) and log-logistic for SPEI (Vicente-Serrano et al. 2010; Vicente-Serrano and Beguería 2016). Data curation and analysis were performed in R (R Core Team 2019) utilizing the “ncdf4” (Pierce 2017), “raster” (Hijmans 2018), “plyr” (Wickham 2011), “abind” (Plate and Heiberger 2016), and “SPEI” (Beguería and Vicente-Serrano 2017) R packages.

For this effort, a drought event is defined when the drought index value is less than −1.5 (signifying principal drought incidents) for at least three consecutive months. Drought assessment for events equal to or more severe than the reference one was performed in a 5-year window. This allows to observe more accurately and in detail the phenomenon than other longer time resolutions (Brito et al. 2018). Drought frequency depicts the number of drought events within a timeframe. Since a 5-year window was adopted, a drought event that might expand on multiple quinquennia is counted at the onset of the event. Duration and severity are demarcated based on the run theory (Yevjevich 1969). An event's duration is defined as the period starting from its onset (threshold exceeded) until the drought index value becomes greater than the same threshold (−1.5). Drought severity is estimated as the integral of the area enclosed between the horizontal line below the selected index threshold and the start-end points of a drought event. Based on these, the pertinent drought characteristics were estimated for Europe from 1969 until 2018, in quinquennia. The results are assessed against independent research comparable findings and the outcomes are presented and discussed.

3 Results and Discussion

3.1 Quinquennia Drought Assessment 1969–2018

Figures 2, 3 and 4 (**maps 1–4**), presents that in the 1969–1973 quinquennium there were droughts in Northern, Central, and Eastern Europe. Southern Europe has experienced no droughts. The highest frequency, duration, and severity for both SPI and SPEI were calculated for Ireland, Scotland, Central Europe, Northern Scandinavia, and Northeastern Russia and to a lesser degree for the Pannonian basin (Serbia and Croatia). A low severity and duration drought was produced for Spain. The 12 month scales exhibit in all drought characteristics a higher intensity. The SPEI values are lesser in most of the cases. Since both indices take into account precipitation, other parameters create the differences, namely evapotranspiration. It would seem that evapotranspiration was not correspondingly decreased, and as air temperature is the dominant parameter, its values were not as high as the precipitation deficits. Noone et al. (2017), reported drought for Ireland in 1969, 1971, and a 53-month duration event in Belfast terminated in 1973, as correspondingly portrayed in Fig. 2 (**maps 1–4**). Dronin and Bellinger (2005) reported a severe drought in north-central Russia in 1972 as portrayed with severe impacts in agricultural production. In Spain, González-Hidalgo et al. (2018) also reported the presented drought. Finally, the portrayed droughts in Germany were well recorded and analyzed with the occurred events being the second-highest during the last 60 years (Khadr et al. 2009; Samaniego et al. 2013).

In quinquennium 1974–1978, the observed results follow the same pattern. Namely, Southern Europe experienced no significant drought. However, an intense heatwave stroked during the annual arid summer period in New Philadelphia, Athens, Greece on the 10th of July 1977, producing the highest temperature ever recorded in continental Europe with 48^0 C (WMO 2019). Correspondingly, Ireland, Wales, England, Germany, Sweden, and Ukraine, experienced the severe drought of 1975–1976, which was also accompanied by a serious heatwave in the UK (Dronin and Bellinger 2005; Marsh et al. 2007; Khadr et al. 2009; Samaniego et al. 2013; Noone et al. 2017). These facts are well portrayed in Figs. 2-4 **(maps 5–8)**, where drought has a medium frequency and magnitude, however a great severity for both SPI and SPEI. Indicatively, drought duration in England and Wales extended from May 1975 – Aug 1976 and its severity reached the second highest after the 2018 drought (Marsh et al. 2007). Furthermore, Noone et al. (2017) stated that the drought in Ireland was the 6th on record for the last 250 years, with a duration of 20 months as also portrayed in Figs. 2, 3 and 4

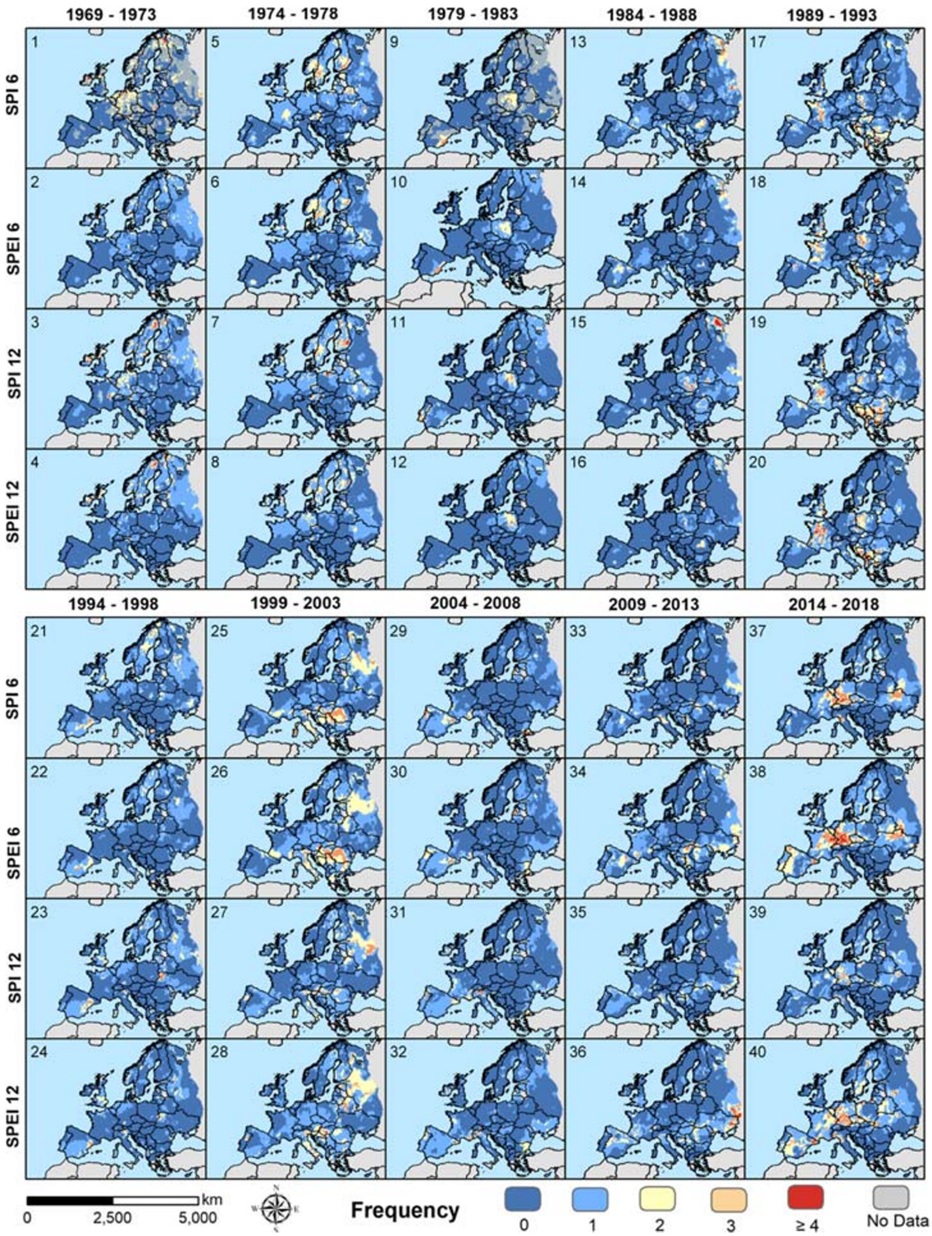

Fig. 2 Quinquennia drought frequency in Europe between 1969 and 2018

(**maps 7–8**) for the 12-month scales. In Germany, the 1975–78 drought was the third most severe on record (Samaniego et al. 2013); and the 1975 drought in Ukraine was the most severe on record up to then (Dronin and Bellinger 2005). Accordingly, the SPEI values lagged those of SPI but followed more closely indicating that correspondingly high air temperature values occurred as recorded.

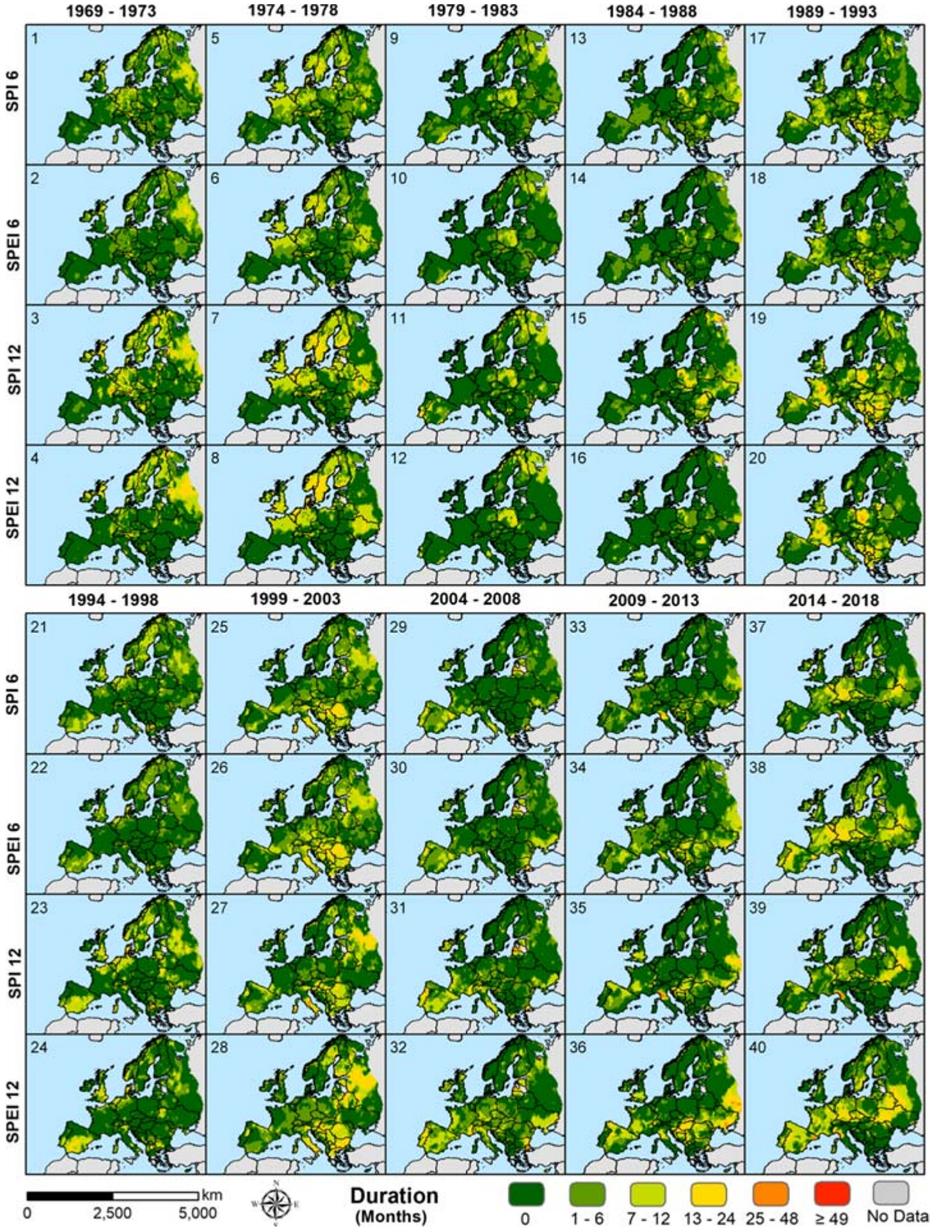

Fig. 3 Quinquennia drought duration in Europe between 1969 and 2018

The 1979–1983 quinquennium identified droughts of medium frequency, duration, and severity in Southern Portugal, Southeastern Spain, Central, and Northern Russia (Figs. 2, 3 and 4 **maps 9–12**). Drought reported for 1980–83 in Portugal (Cabrinha and Santo 2000; Santos et al. 2010) as portrayed in Figs. 2, 3 and 4 (**maps 9–12**). González-Hidalgo et al. (2018) also reported Spain droughts in 1981 with a duration of 8 months portrayed by SPI-12 and in 1983 with a three-month duration. Golubev and Dronin (2004) reported drought in Russia for 1981

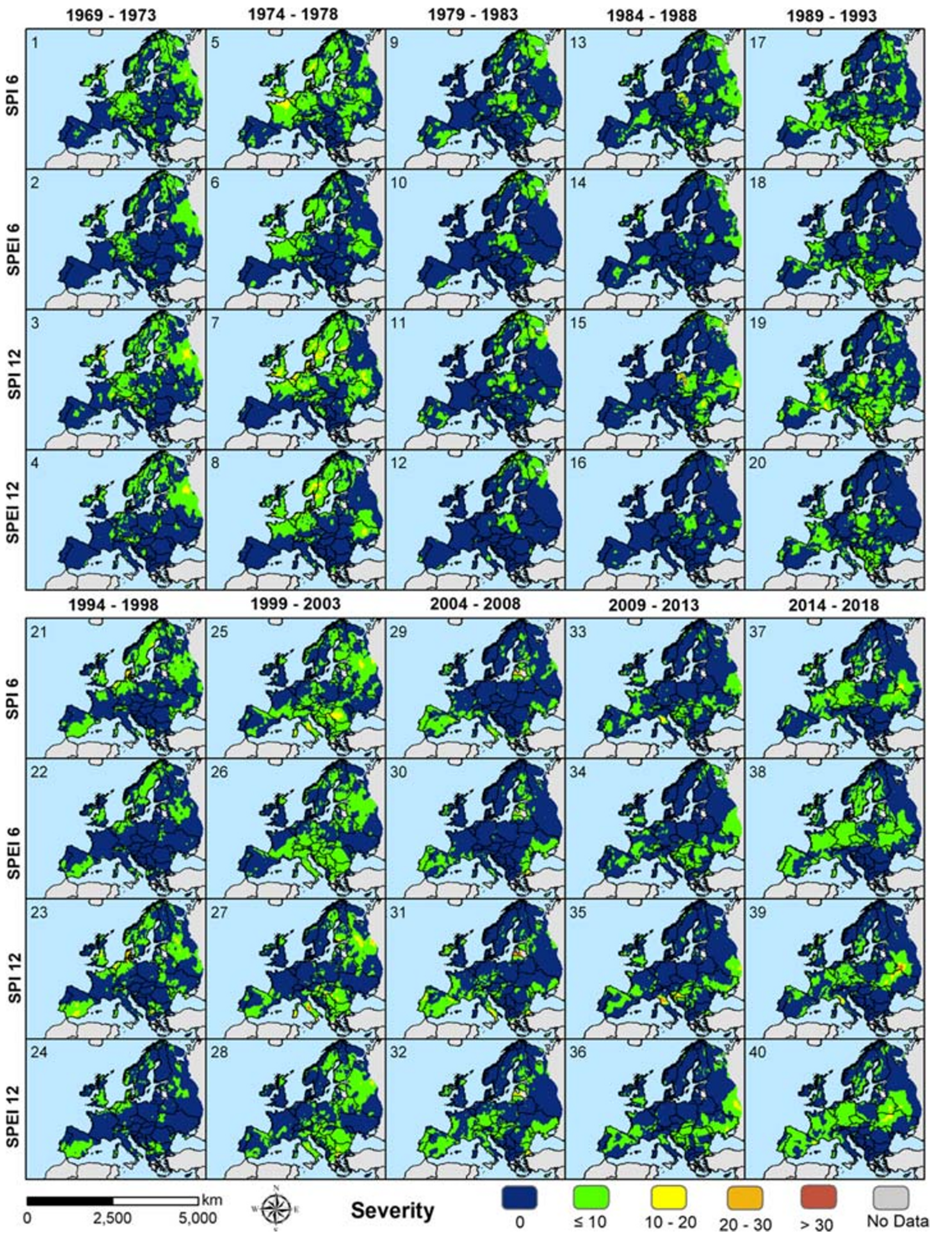

Fig. 4 Quinquennia drought severity in Europe between 1969 and 2018

as depicted. Again, the SPEI lagged with lower values than those of SPI. No drought incidents are produced for the rest of Europe as also not recorded in the literature.

In the 1984–1988 period (Figs. 2, 3 and 4 **maps 13–16**), drought manifests itself in Northern Spain and Southwestern France with both SPI and SPEI of medium frequency and low duration and severity. Such findings were correspondingly reported for 1986 by González-Hidalgo et al. (2018). For Romania, Central, and Northern Russia, as well as Northern Norway the indices exhibit medium to high frequency, duration, and severity. Golubev and Dronin (2004) reported correspondingly a drought on Central Russia in 1984. A low value in SPI-6 frequency is presented for southern Europe, but with very low duration and severity. Again, the SPEI values are lagging those of SPI, however with a higher concentration in Southern Europe. Correspondingly, a record-breaking heat wave having eight consecutive days with temperatures equal or above 41° Celsius recorded in Athens, Greece, from 22nd to 30th of July 1987 resulting in a toll of more than 1300 human lives (Documento.gr 2017).

Figures 2, 3 and 4 **(maps 17–20)**, denote that in the 1989–1993 period drought appeared all over Europe except Scandinavia. The highest frequency duration and severity are displayed for Southeastern Europe. Such findings coincide with the rich drought literature reports of the period, as Cabrinha and Santo (2000) and Santos et al. (2010) demarcated the 1990–1992 drought in Portugal. González-Hidalgo et al. (2018) pinpointed the 1992 drought in Spain. Hamer (1990) commented that the 1989–1990 drought was the second-highest for the U.K., after the event in 1976. For Germany, the 1990–1993 period was the sixth biggest of the previous 60 years Samaniego et al. (2013). Ukraine and Russia for 1991–1992 also experienced drought (Golubev and Dronin 2004; World Bank 2018). The 1989–1993 drought in Greece is still the most severe on record (Karavitis (1999); Karavitis et al. (2012, 2014). In October 1990 Athens had water reserves for only 56 days despite the extensive water storage infrastructure. Overall, in this quinquennium, the SPEI follows more closely the SPI values, particularly for Southeastern Europe.

In the 1994–1998 quinquennium **(**Figs. 2, 3 and 4 **maps 21–24)**, drought befalls in Ireland with high frequency and severity, but low duration, as correspondingly reported for 1995 by Noone et al. (2017). Drought is also portrayed in Portugal with medium to high characteristics, as Cabrinha and Santo (2000) and Santos et al. (2010) respectively recorded. Drought is also depicted in Northern Spain and Southwestern France with both SPI and SPEI of medium to high characteristics. González-Hidalgo et al. (2018), reported similarly a drought in 1994–1995 having an 18-month duration. For Germany, low to medium frequencies, duration, and severity are displayed. Samaniego et al. (2013) reported correspondingly that the 1995–1997 drought was the eighth largest in the previous 60 years. A drought with medium to high characteristics is presented in Figs. 2, 3 and 4 (**maps 21–24**), for Hungary and Romania, as respectively reported (DMCSEE 2019). Finally, both SPI and SPEI display low to medium drought characteristics for Ukraine and Russia. The corresponding drought was also independently presented for 1995–1996 (World Bank 2018). However, in this quinquennium, the SPEI values are following closely those of SPI, possibly because equally high air temperature values were inflicted. For Greece, SPI and SPEI are indicating minimal drought characteristics, as similarly normal hydrologic conditions reported after 1995 (Karavitis 1999).

Figures 2, 3 and 4 **(maps 25–28)**, from 1999 to 2003 show a low duration and severity drought for Portugal, as also recorded for 1999 (Cabrinha and Santo 2000; Santos et al. 2010). A medium frequency, but of low duration and severity drought is displayed in Spain in 1999 and 2002, as also presented by González-Hidalgo et al. (2018). In Russia and Ukraine, a low to medium frequency and a high duration and severity drought is pictured, as also presented for 1999 and 2003 (World Bank 2018). Finland was distressed by a nine-month drought from August 2002 to April 2003 (Spinoni et al. 2015; Di Liberto 2018), as portrayed in Fig. 3 **(maps 25–28)**. Overall, SPI and SPEI have close values for the droughts. No significant droughts were detected for the rest of Europe as also recorded in the literature.

Figures 2, 3 and 4 **(maps 29–32)** portray drought for most of Europe in 2004–2008 with SPI and SPEI displaying medium to high characteristics. England, Wales, and Ireland experienced low frequency and duration, but high severity drought, as also recorded for 2006 by Noone et al. (2017). Portugal shows low to medium frequency and duration, however high severity as reported from 2004 to 2005 (Santos et al. 2010; Maia et al. 2015). Spain exhibits low frequency, and severity, but long drought duration. González-Hidalgo et al. (2018) presented also corresponding droughts for 2002 and 2005–2006, the latter with more than 11 months duration. In France, there is low to medium frequencies, duration, and severity, as also recorded by Vidal et al. (2010) for 2003. For Germany, medium to high characteristics are presented. Correspondigly Samaniego et al. (2013) stated that 2003–2005 was the seventh biggest drought in the previous 60 years for Germany. Figures 2, 3 and 4 **(maps 29–32)** present drought with low to medium characteristics for Slovenia, Hungary, Slovakia, Czech, and Romania, as reported accordingly for 2004 (DMCSEE 2019). SPI and SPEI of medium to high drought characteristics are displayed for Ukraine and Russia with a corresponding drought independently presented for 2004 and 2007–2008 by World Bank (2018). Southeastern Europe (south Italy, Albania, Northern Greece, and eastern Romania) and northern Europe, including Scotland and most of Scandinavia, were not affected by drought. Furthermore, in 2006–2007 southern Greece suffered a medium drought causing the initiation of drought management measures (Karavitis et al. 2014). Compounding to drought, on June the 26th 2007 a record-breaking temperature of 44,8 °C in Thesseion, Athens was recorded, with the previous record being 43 °C on June the 21st 1916 (Documento.gr 2017). Overall, SPEI scored generally higher than SPI indicating high air temperatures, as recorded respectively for 2003–2005 for France and Germany (Vidal et al. 2010; Samaniego et al. 2013).

During the 2009–2013 quinquennium, both indices score medium to high, except for southeastern Spain, southern Italy, southeastern Europe, and Eastern Russia (Figs. 2, 3 and 4 **maps 33–36**). Northwestern Italy, western and central Europe, southern Sweden and Finland, display mostly medium values in frequency, duration, and severity. González-Hidalgo et al. (2018) described a six-month duration drought for 2012 in Spain. Bissolli et al. (2012) presented similar findings for Germany and central Europe in 2011–2012. Furthermore, they reported that total precipitation was in the 10th percentile in 2012 for central Europe and the southwestern Iberian Peninsula, while southeastern Europe enjoyed normal conditions. They also stated that south Sweden suffered a drought as well as half of the UK. World Bank (2018) respectively recorded a drought for central Russia and Ukraine in 2012.

In the last quinquennium, both SPI and SPEI exhibit medium to high frequencies, duration, and severity for western, central, and northern Europe (Figs. 2, 3 and 4 **maps 37–40)**. Such findings recorded for droughts striking central Europe, northern Italy, and Spain with exceptionally high temperatures in 2015 (EU 2016). Another severe drought has stricken central and northern Europe in 2018 (Oikonomou et al. 2018). Southeastern Europe experienced no droughts, as also recorded.

3.2 Semi-Centennial 1969–2018

The drought frequencies presented by SPI and SPEI for the entire 50 year period exhibit an even drought incidents distribution throughout Europe (Fig. 5). From Fig. 5 and the presented analyses, it may be derived that droughts have been occurring indiscriminately of locales east and west north and south. However, they have a strong temporal orientation directly associated with the annual climatic precipitation distribution (i.e, higher precipitation in winter for the Mediterranean area, as opposed to higher summer rainfalls in Central and Northern Europe). Specifically, SPI-6 has an even drought frequency distribution with no particular region to

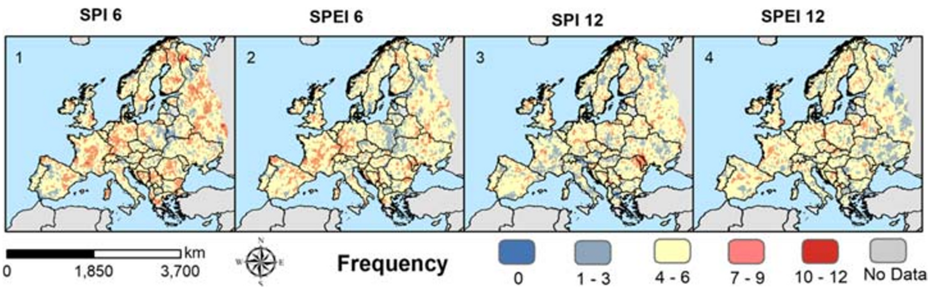

Fig. 5 Drought frequency in Europe for the period 1969–2018

display solely a very high drought frequency concentration. Looking also in combination with the presented quinquennium analysis up to 1988 (Figs. 2, 3 and 4 **maps 1–16**), Central and Northern Europe experienced far more droughts than the Southern part of the continent, a fact also recorded in the literature (Dronin and Bellinger 2005; Marsh et al. 2007; Khadr et al. 2009; Santos et al. 2010; Samaniego et al. 2013; Noone et al. 2017; González-Hidalgo et al. 2018). Then as portrayed and analyzed in Figs. 2, 3 and 4 (**maps 17–28**), from 1989 up to 2003, southern Europe is experiencing many severe droughts with fewer incidents in the Central and Northern Europe, as it is also described in the literature (Golubev and Dronin 2004; Vidal et al. 2010; Karavitis et al. 2012; Samaniego et al. 2013; Karavitis et al. 2014; World Bank 2018) Overall, from the presented analyses the 1990–2005 period inflicted the most severe droughts for all Europe. Then, from 2004 up to 2018, central and northern Europe become the drought hot spots, with far fewer incidents in the southern part mainly located in the Iberian Peninsula (Figs. 2, 3 and 4 **maps 29–40**), as also recorded (Marsh et al. 2007; Bissolli et al. 2012; Samaniego et al. 2013; Maia et al. 2015; Noone et al. 2017; Oikonomou et al. 2018; González-Hidalgo et al. 2018). By examining all the quinquennia, the overall frequency analyses, no apparent tendency towards progressively more drought incidents may be reported for the last fifty years, as also independent research indicated (Bissolli et al. 2012; Martins et al. 2012; Sheffield et al. 2012; Hanel et al. 2018). However, trend analysis in a new research effort seems necessary to be conclusive on the subject. Nevertheless, any drought management efforts should take in serious consideration droughts in previous periods as research has revealed far more severe droughts in the past couple of centuries than the ones occurred during the examined period (Dronin and Bellinger 2005; Samaniego et al. 2013; Noone et al. 2017; Brázdil et al. 2018).

4 Conclusions

This effort presented a pan-European drought assessment for the last 50 years focusing on drought characteristics: frequency, duration, and severity. The E-OBS gridded datasets (0.25-degree spatial resolution) for precipitation, minimum temperature, and maximum temperature for the period 1969–2018 employed to derive the SPI and SPEI. It is underlined, as also pertinent research has recommended, to avoid time scales of 3-month or shorter for the indices estimation, since southern Europe exhibits characteristics with extremely low precipitation during summers. The indices were estimated with time scales of 6 and 12 months to characterize more accurately droughts and the analysis results to be comparable across the continent.

The presented assessment of the SPI and SPEI metrics emphasizes the extensive diversity and multiplicity of drought in terms of frequency, duration, and severity across Europe. Seemingly, one of the central outcomes of this research is that there is little change in drought characteristics for 1969–2018. It also seems, no particular tendencies for more or less frequent droughts in the two major geographical domains of Europe are present. This reinforces the stochastic nature of the drought natural hazard. Further research is required incorporating longer time records and data in areas left out of this analysis (e.g. southern Italy and Greece) and dedicated new research on drought trend analysis to assess drought characteristics more accurately, as well as to apply the methodology in regional or local area scale. Particularly for drought contingency planning, a larger time envelope is essential to include the more severe drought events that occurred in the past.

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Compliance with Ethical Standards

Conflict of Interest None.

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