Bulgarian Geophysical Journal, 2014, Vol. 40
National Institute of Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences

POSSIBILITY FOR DROUGHT ASSESSMENT WITH GRIDDED DATA-SETS OF THE STANDARDIZED PRECIPITATION INDEX

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Abstract. Drought Indices (DIs) have been commonly used to define drought conditions. In general, DI is a function of several hydro-meteorological variables and can be integrated in a decision support system as a drought management tool to trigger drought relief programs. Globally, droughts have been studied using many different indicators, but, among them, the Standardized Precipitation Index (SPI) has significant advantages. SPI has been selected by the World Meteorological Organization (WMO) as a key indicator for monitoring drought ('Lincoln declaration') and is one from the two most used in Europe. The obtained from the authors' four global gridded data-sets of the SPI are presented. They are computed from the UDEL/GEOG/CCR v3.02, GPCC v7.0, the NOAA-CIRES 20CR v2c and the ECMWF ERA20C monthly precipitation databases and each of them is with more than a century long time extent. The SPI is calculated for the most frequently used time scales of 1, 3, 6, and 12 months and, except ECMWF ERA20C, are in the highest available grid resolution, native for the precipitation database. The popularity of the SPI in the geophysical community and the strong conviction of the authors that the free exchange of data and software services are basis of effective scientific collaboration, are the main motivators to open the produced data-sets for free of charge download. The paper shows also in concise form some possible use of this information, revealing its suitability for various objective long-term drought studies at any geographical position.

Key words: Global Gridded Data-sets of SPI, Objective Drought Assessment, Free SPI-data Download

Introduction

Drought is a natural phenomenon and poses significant problems around the world. It places huge demands on rural and urban water resources, and enormous burdens on agricultural and energy production. In general, drought is defined as the water scarceness due to insufficient precipitation, high evapotranspiration and over-exploitation of water resources or a combination of these parameters. Despite its complex nature, there is overall agreement that precipitation is the primary factor controlling the formation and persistence of drought conditions. Drought indices (DIs) have been commonly used to define drought events. In general, DI is a function of several hydro-meteorological variables (e.g., rainfall, temperature, streamflow, snowmelt, etc.). They can be integrated in a decision support system as a drought management tool to trigger drought relief programs. Moreover, it has been used to quantify deficits in water resources and as a drought monitoring tool. However, drought researchers are confronted with the ambiguity of drought definitions and DIs, which has never been resolved to the satisfaction of all drought researchers and professionals. In attempt to overcome this, an Inter-Regional Workshop on Indices and Early Warning Systems for Drought was held at the University of Nebraska-Lincoln in December, 2009. It was jointly sponsored by the School of Natural Resources of the University of Nebraska, the U.S. National Drought Mitigation Center, the World Meteorological Organization (WMO), the U.S. National Oceanic and Atmospheric Administration (NOAA), the U.S. Department of Agriculture (USDA), and the United Nations Convention to Combat Desertification (UNCCD). The workshop reviewed the drought indices currently in use in different regions of the world to explain meteorological, agricultural and hydrological droughts, assessed the capacity for collecting information on the impacts of drought, reviewed the current and emerging technologies for drought monitoring and discussed the need for consensus standard indices for describing different types of droughts. Manifestation of the results of the conference is the Lincoln declaration (Hayes et al. (2011)), which key point is that the workshop came to a consensus that the Standardized Precipitation Index (SPI) be used to characterize the meteorological droughts around the world. More specially, the National Meteorological and Hydrological Services (NMHSs) around the world are encouraged to use the SPI to characterize meteorological droughts and provide this information on their websites, in addition to the indices currently in use. The free availability in the recent decades of digital maps for the monthly precipitation sums, either from objective analysis or from reanalysis, has encouraged the authors to compute the SPI for the frequently used time scales of 1, 3, 6, and 12 months (noted traditionally as SPI-1, SPI-3, SPI-6 and SPI-12) from four sources for the full time length of each precipitation data-set. Consequently, following our strong conviction that the free exchange of data and software services are basis of effective scientific collaboration, we offer these results for free of charge download via Internet. Mean aim of this study is to present shortly these data-sets, rather than to perform any drought climatology. Thus, the listed examples have to be treated as small illustration of the variety of potential applications at any possible geographical position, depending of the particular interest of each end-user.

The paper is organized as follows: Section 2 provides a description its strengths, limitations and application of the SPI for objective drought assessment. The third section contains concise description of the used precipitation data-sets. The performed calculations, validation of the output are in the fourth section. The procedure for the free of charge download of the output data-sets is described in the fifth. In the sixth section are listed some illustrative examples and the short summary and conclusion are placed in the last, seventh section.

Theoretical aspects, strengths and limitations of the SPI

The SPI was developed by McKee et al. (1993) for monitoring drought conditions based on precipitation sums. It is computed by fitting a cumulative probability function (CPF) to the distribution of precipitation summed over the time scale of interest. This is performed separately for each month (or whatever the temporal basis (time window) is of the raw precipitation time series) and for each location in space.

The definition of the SPI is part of many publications, and thus will be not addressed here. The reader can find it, for example, in Lloyd-Hughes and Saunders (2002). Once standardized, the strength of the anomaly is classified as set out in Table 1. The table also contains the corresponding probabilities of occurrence of each severity, these arising naturally from the normal probability density function.

SPI value	Category	Probability %
2.00 or more	Extremely wet	2.3
1.50 to 1.99	Severely wet	4.4
1.00 to 1.49	Moderately wet	9.2
0 to 0.99	Mildly wet	34.1
0 to −0.99	Mild drought	34.1
−1.00 to −1.49	Moderate drought	9.2
−1.50 to −1.99	Severe drought	4.4
−2 or less	Extreme drought	2.3

Table 1. Values of SPI and corresponding categories and probabilities (after Lloyd-Hughes and Saunders (2002))

In the recent decade the SPI is widely used throughout the world in both a research and an operational mode (see Lloyd-Hughes and Saunders (2002) for details).
In many articles (see, for instance, Hayes et al. (1999)) the advantages and disadvantages of using the SPI for drought severity assessment are discussed. The SPI has three main advantages. The first and primary advantage is simplicity. The SPI is based solely on rainfall and requires only the computation of two parameters, compared with the 68 computational terms needed to describe the popular Palmer drought severity index (PDSI). By avoiding dependence on soil moisture conditions, the SPI can be used effectively in the whole year. The SPI is also not affected adversely by topography. The SPI's second advantage is its variable time scale, which allows it to describe drought conditions important for a range of meteorological, agricultural, and hydrological applications as in the cited articles above. This temporal versatility is also helpful for the analysis of drought dynamics, especially the determination of onset and cessation, which have always been difficult to track with other indices. The third advantage comes from its standardization, which ensures that the frequencies of extreme events at any location and on any time scale are consistent. Other strength, usually dismissed in the SPI description, is that this index is defined without any empiricism, in particular 'local parameterizations', which, more or less, are connected to the concrete position and/or data-set. This problem arises also in the attempts to generalize the SPI, including the evapotranspiration (see Vicente-Serrano

(2012)). The SPI has three potential disadvantages, the first being the assumption that a suitable theoretical probability distribution can be found to model the raw precipitation data prior to standardization. An associated problem is the quantity and reliability of the data used to fit the distribution. A second limitation of the SPI arises from the standardized nature of the index itself; namely that extreme droughts (or any other drought threshold) measured by the SPI, when considered over a long time period, will occur with the same frequency at all locations. Thus, the SPI is not capable of identifying regions that may be more 'drought prone' than others. A third problem may arise when applying the SPI at short time scales (1, 2, or 3 months) to regions of low seasonal precipitation. Strictly speaking, the SPI is not defined by zero precipitation. In these cases, misleadingly large positive or negative SPI values may result. On this problem partly is dedicated the work of Wu et al (2012). On the basis of the results identified within this study, the authors recommend that the SPI user be cautious when applying short-time-scale SPIs in arid climatic regimes, and interpret the SPI values appropriately.

Used data

In the recent decades objective analysis and reanalysis have been extensively developed in many institutions and, consequently, the produced data-sets used in many applications. In our study we have used two objective analysis data-sets, namely the version 3.02 of the "Terrestrial Precipitation: 1900-2010 Gridded Monthly Time Series" of the Department of Geography of the University of Delaware (Peterson et al (1998)), noted further as UDEL and the Global Precipitation Climatology Centre (GPCC) Full Data Reanalysis version 7.0 (Schneider et al (2015)), noted as GPCC. The both are global and the subsets with the highest resolution of 0.5°×0.5° for both are considered for the SPI-calculation. The time extent of UDEL is 1900-2010 and of GPCC - 1901-2013. The considered reanalysis data-sets are the version v2c of the NOAA-CIRES 20CR (Compo et all. (2011)) noted as CIRES and ERA20C of the European Centre for Medium-Range Weather Forecasts (ECMWF) noted further as ERA20C (Stickler et al (2014)). These data-sets are also global with time coverage 1851-2011 and 1900-2010 correspondingly. The row data of CIRES are in Gaussian irregular grid and are interpolated with the tool "cdo" (http://www.mpimet.mpg.de/cdo) to the 1.5°×1.5° resolution with similar to the original grid cell size. So, one CIRES gridcell accommodate nine UDEL or GPCC ones. The ERA20C data-set is deliberately downloaded with 0.5°×0.5° resolution although the grid-cell centers are offset by 0.25 deg in comparison to UDEL and GPCC.

Performed calculations and validation

The values of SPI-1, SPI-3, SPI-6 and SPI-12 are computed using own programs, following the classical approach, proposed by McKee et al. (1993). The calculations are performed over the whole spatial and temporal extent of each input data-set, described in previous section.

The web site of the CARPATCLIM project (see JRC report (2010) and the references therein) contains data for monthly precipitation sums and the calculated with them SPI and thus are suitable for validation of our calculation procedures. The two computations were found to be in excellent agreement. The European Drought Observatory of the Joint Research Centre (EDO-JRC, http://edo.jrc.ec.europa.eu/edov2/php/index.php?id=1000) publishes also SPI maps of recent drought episodes. Although computed with SYNOP data and different reference period they are very close to our results.
The selection of the reference period for the calculation of the CPF parameters is usually not commented with necessary depth, but, this is very relevant. McKee et al. (1993) recommends to use time-series with at least 30 years length and thus the current WMO standard reference period 1961-1990 seems the most natural choice. Considering the results of an inventory of the reference periods used in various Member States, the specific needs for accurately representing extreme events, and possible changes in the rainfall regimes due to climate change, the Water Scarcity and Drought Expert Group strongly recommends using the period January 1971 to December 2010 as Reference Period for the calculation of the SPI.

Illustrative examples and qualitative comparisons

Main result from the presented work are the spatial and temporal arrays of the fourth SPIs, retaining the spatial and temporal extent/resolution of the corresponding input precipitation data-set. Such distribution facilitates the combined analysis of both in parallel. Hence each map, drawn after interpolation of unstructured data, for instance the point measurements in the SYNOP stations as in the work of Karavitis et al (2011), depends from the subjective choice of the interpolation procedure, the presented here in the 'native' regular grid data-sets are much more consistent.
As far as any drought climatology is beyond the scope of the presented work, only some illustrative examples, which reveals possible implementations of the data-sets, will be listed concisely.
Thus Figure 1 shows the world map of the SPI-12 for the second year of the NOAA-CIRES reanalysis.

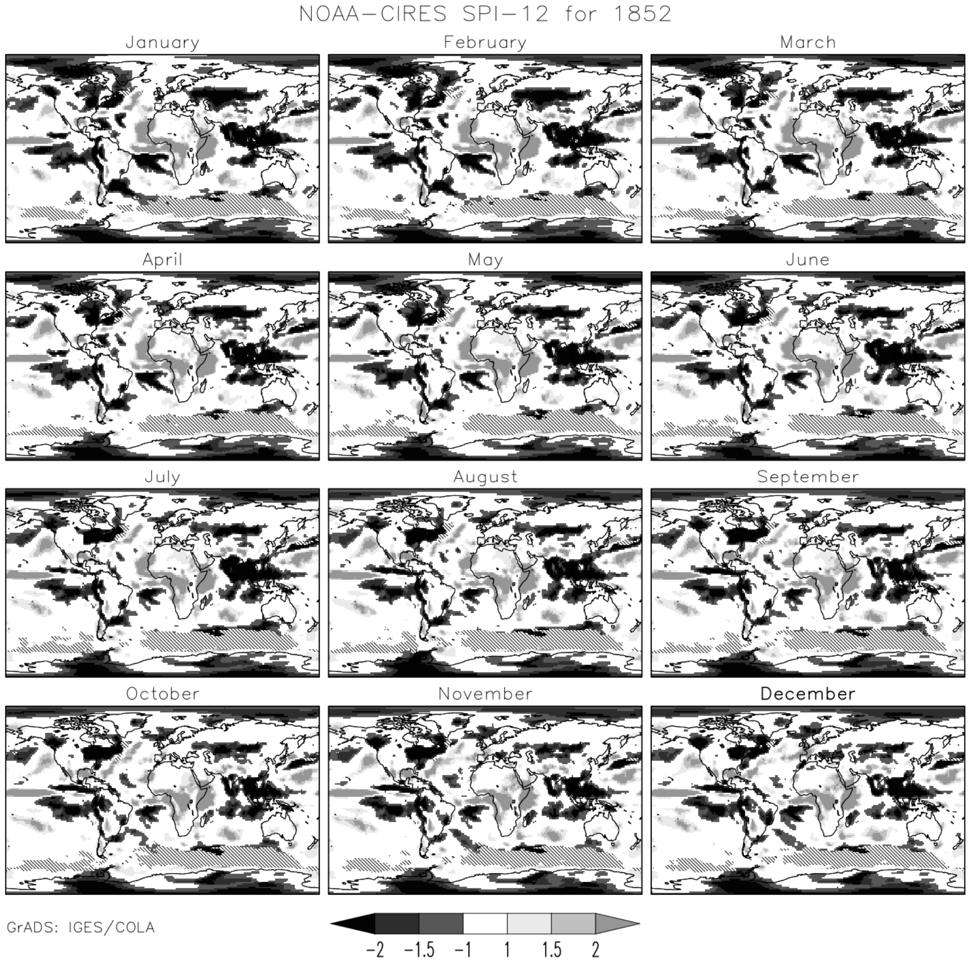

Fig. 1. World map of the SPI-12 for the second year of the NOAA-CIRES reanalysis

The drought in the USA during 1976 and 1977 was well expressed, especially in particular regions; California's statewide snowpack reached an all-time low in 1977. The spatial distribution of the SPI-6 for North America for this year is depicted on Figure 2.

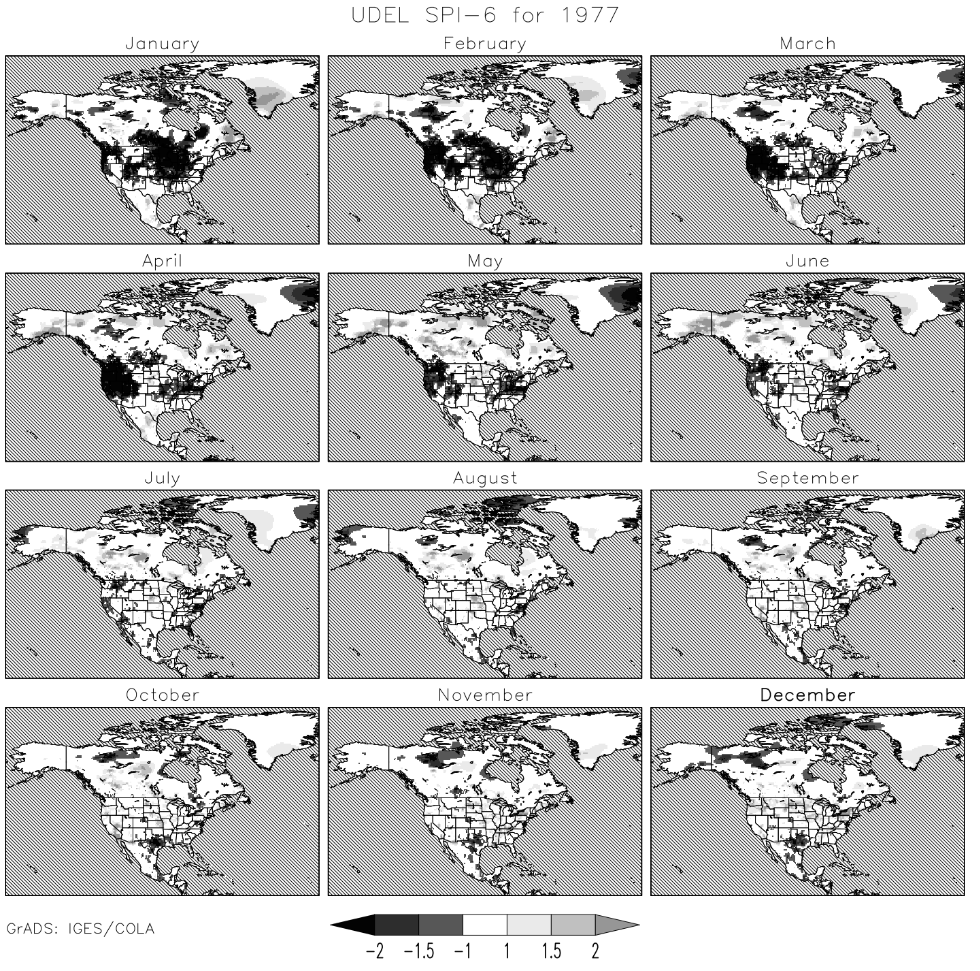

Fig. 2. Map of the SPI-6 for 1977 obtained from UDEL. Hence this dataset contains data for the land-surface only, the SPIs over the water bodies are undefined and shown hatched.

The extreme drought and heat wave that hit Europe in the summer of 2003 had enormous adverse social, economic and environmental effects, such as the death of thousands of vulnerable elderly people, the destruction of large areas of forests by fire, and effects on water ecosystems and glaciers. It caused power cuts and transport restrictions and a decreased agricultural production. According to the on-line document (http://www.unisdr.org/files/1145_ewheatwave.en.pdf) "Impacts of summer 2003 heat wave in Europe" of the United Nations Environment Programme (UNEP) the losses are estimated to exceed 13 billion euros. Map for SPI-3 for this episode is shown on Figure 3.

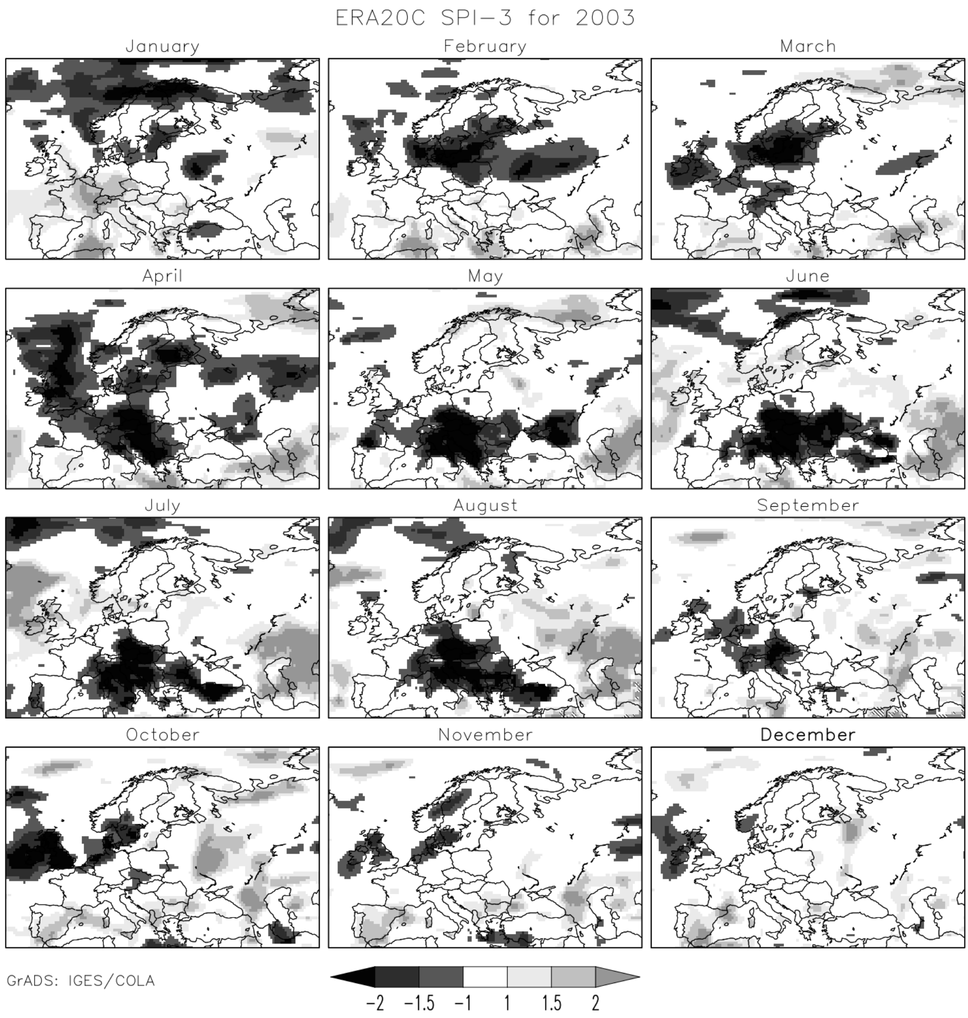

Fig. 3. Map of the SPI-3 for 2003 obtained from ERA20C

Typical issue of the long-term drought climatology is the analysis of historical drought events. So, for instance, the EDO-JRC maintains drought episodes site, which is updated periodically. Impressive is the case in 1989-1991 in Europe, which, according this source is in the list of 21 biggest droughts since 1950. Especially affected ware Southern Europe and the Mediterranean. Figure 4 shows the spatial distribution of the SPI-1 in the middle year, 1990 for Southeast Europe.

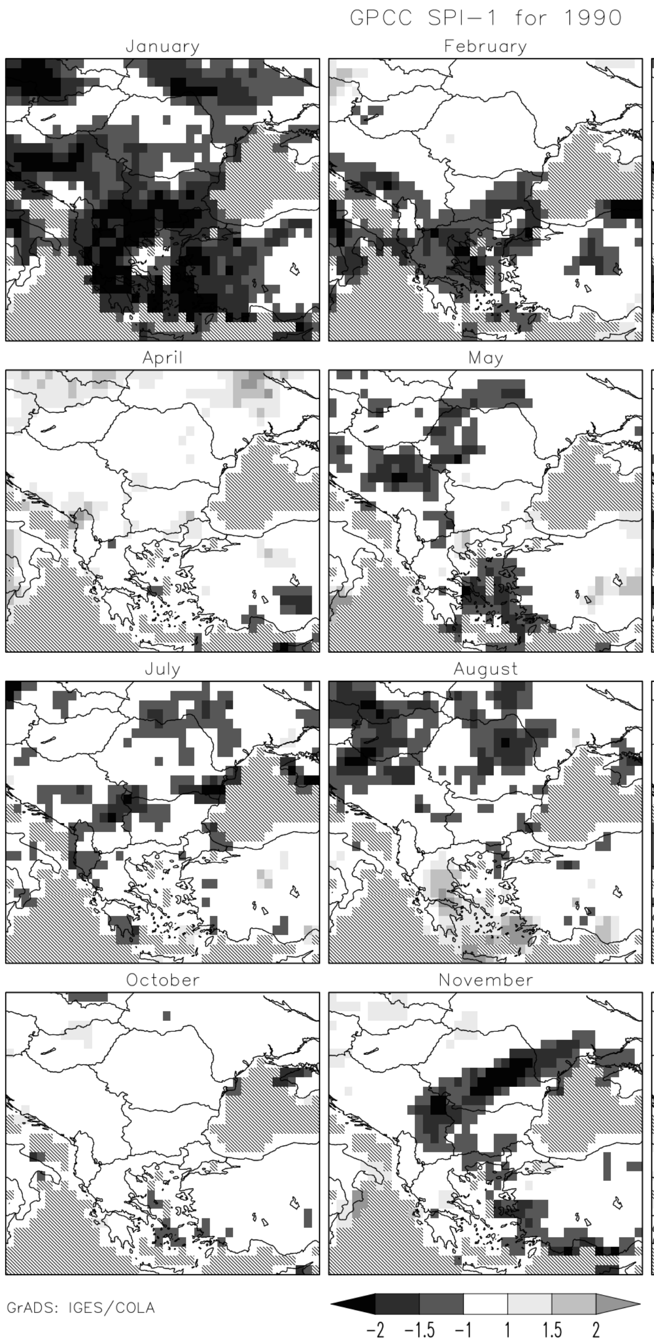

Fig. 4. Map of the SPI-3 for 2003 obtained from GPCC. This data-set contains data also for the land-surface only.

The obtained data-sets can be post-processed statistically in order to derive some secondary measures, which are suitable for climatological analysis. So, for instance, Lloyd-Hughes and Saunders (2002) shows, among other results, maps of the number of drought events, where the individual ones are defined by zero crossings that bound the exceedance.
Finally, the presented data-sets offers the possibility to extract certain information in particular (grid) point of interest in form of time series, which is other traditional way for data analysis and visualization, as shown on Figure 5.

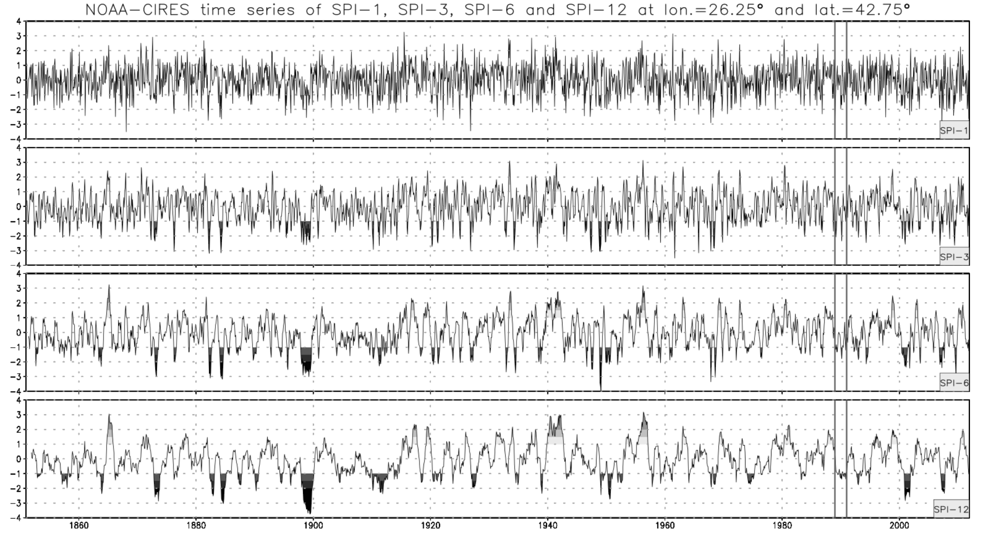

Fig. 5. Time series of SPI-1, SPI-3, SPI-6 and SPI-12 for grid point located in SE Bulgaria. The vertical grey lines brackets 1989-1991, which is drought period.

To save place, only the time series of the SPIs, of the data-set with the longest time-span, NOAA-CIRES are plotted. Such subsets can be also post-processed, especially applying techniques for trend analysis or for searching of periods of cyclic repetition of predefined anomalies.

Data-sets download

The output data-sets are written in the standard meteorological file format netCDF and are available for free of charge download at ftp://xeo.cfd.meteo.bg/SPI/.
If you acquire these data, we ask that you acknowledge us in your use of the data. This may be done by including text such *the SPI data-set are prepared from Chervenkov at al. from the Bulgarian National Institute of Meteorology and Hydrology* in any documents or publications using these data. We would also appreciate receiving a copy of the relevant publications. Thank you in advance!

Summary and conclusion

Although many researchers argue that rainfall based DIs are not strong enough to define the wider drought conditions, their appropriateness was proven in numerous studies in most parts in the world. Despite their limitations, these indicators offer pragmatic approach for quantitative estimation of complex phenomena. This fact is strengthened since the rise of the digital era, when reliable data-sets of plenty of meteorological and hydrological parameters are freely available. This allows the calculation of such 'secondary' quantities as the SPI routinely for climatologically significant periods of time (in order of decades) practically all over the world.

Despite of the similarity in the precipitation sums for fixed time and location between the fourth input data-sets, they are generally not equivalent and, more or less, this reflects to the corresponding SPI-arrays. This specific have to be accounted in certain applications.

The presented data-sets and their availability a priori (i.e. before the start of any drought study) saves time and computational efforts of the potential user allowing him to focus his attention to the relevant analysis and interpretation. The data-sets can be used from wide circle of investigators and decision-makers solely or, as is our advice, in combination and/or addition with other methods achieving comprehensive drought assessment in every region of interest.

Acknowledgment. This study is entirely based on free available data and software. The authors wood like to express their deep gratitude to the organizations and institutes (University of Delaware, GPCC/DWD, ECMWF, NOAA, NCEP-NCAR, Unidata, MPI-M and all others), which provides free of charge software and data. Without their innovative data services and tools this study would be not possible. Thanks also to all third-party organizations for the funding: Support for the Twentieth Century Reanalysis Project version 2c dataset is provided by the U.S. Department of Energy, Office of Science Biological and Environmental Research (BER), and by the National Oceanic and Atmospheric Administration Climate Program Office. The authors are grateful to Dr. E. Dutra at ECMWF for the valuable suggestions.

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Възможност за анализ на засушаване чрез набор данни в равномерна мрежа за стандартизирания валежен индекс

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Резюме: Използването на индекси за засушаване (ИЗ) е често прилаган метод за оценка на условията за засушаване. Като цяло, ИЗ са функция на различни хидро-метеорологични променливи и могат да бъдат интегрирани в комплексни системи за митигация на последствията. В световен мащаб се прилагат множество ИЗ, но Стандартизираният Валежен Индекс (SPI) има значителни преимущества пред останалите. SPI е избран от Световната метеорологична организация (СМО) като ключов индикатор за наблюдение на засушаването (вж. т. нар. «Дакларация от Линкълн») и е един от двата най-често прилагани в Европа. Статията представя четирите получени от авторите глобални набори данни за SPI в равномерна мрежа. Те са изчислени съответно чрез UDEL/GEOG/CCR v3.02, GPCC/ v7.0, NOAA-CIRES

20CR v2c и ECMWF ERA20C бази данни за месечния валеж като всяка от тях е с времеви обхват повече от век. Индексът е изчислен за най-често използваните времеви мащаби от of 1, 3, 6 и 12 месеца и, с изключение на ECMWF ERA20C, са в най-голямата резолюция, в която са налични данните за валежа. Популярността на SPI в експертната общност и силното убеждение на авторите, че свободния обмен на данни и програмни средства е основа за ползотворно научно сътрудничество, са главните мотиви за предоставянето на получените набори за свободен достъп. В конспективен стил е показана и приложимостта на резултатите за различни дългосрочни обективни изследвания в произволен географски район.