Assessment of multi-scale drought datasets to quantify drought severity and impacts in agriculture: a case study for Slovenia*

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Abstract

Real-time information on the development of the drought conditions is one of the fundamental requisites for reinforcing the drought mitigation and preparedness. The EuroGEOSS interoperability approach promotes the development of monitoring and early warning systems based on real-time information. Different climatic databases, which are based on publicly available meteorological information, are available on real time by climatic research institutions. Commonly, publicly available information has much lower spatial resolution than the existing available national datasets. The capability of low resolution climatic datasets to quantify drought severity and drought impacts is limited and has therefore been analysed in the framework of the EuroGEOSS project. Initial operating capacity, which was built during the project, provided the framework for the analysis. The Standardized Precipitation Index, obtained from the low-resolution precipitation datasets, has been compared to the national high-resolution datasets in Slovenia. The areas of low spatial agreement between different drought datasets were determined. In addition, various statistical measures were used to compare the drought characteristics, originating from different drought datasets. Furthermore, the capabilities of these datasets to

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identify the drought impacts in different drought prone systems were analyzed. Even though, low resolution datasets failed to realistically detect the spatial patterns of specific drought episodes, they were able to reproduce the general drought temporal variability, especially at the short time scales. The low resolution dataset also provided reliable outputs in terms of knowing the impacts of drought on agriculture.

Keywords: interoperability, EuroGEOSS, DMCSEE, European Drought Portal, drought monitoring, Standardized Precipitation Index, agricultural drought, maize yield, water balance

1. INTRODUCTION

Drought is a naturally occurring event that is associated with virtually all climatic regions. Drought has several characteristics that make analysing, monitoring and management very complex. These conditions are more difficult to identify than other natural hazards because of the drought long-term development and duration, progressive character of its impacts and diffuse spatial limits (Wilhite, 1993). It is commonly accepted that drought is a multi-scalar phenomenon; McKee et al. (1993) illustrated this essential characteristic of droughts through consideration of usable water resources including soil moisture, ground water, snowpack, river discharges and reservoir storages. The time period from the arrival of water inputs to availability of a given usable resource differs considerably. Thus, the time scale over which water deficits accumulate, becomes extremely important, and functionally separates hydrological, environmental, agricultural and other types of drought. Impacts of drought in these sectors are difficult to assess and have been mainly documented only partially by national drought monitoring systems. Other research organizations play important role when assessing the impact of drought (e.g. damage that is caused by drought on crop yield, is mainly monitored by Agricultural Institute in Slovenia). High level of data dispersion among different data providers makes it difficult to assess the impact of climatic droughts on crop production, which therefore remains poorly understood.

Drought indices, which are used for monitoring drought conditions, must be associated with a specific timescale in order to be useful for the monitoring and management of different usable water resources and to identify impacts on ecosystems and crops since the time of response of different vegetation species to water availability varies greatly (Ji and Peters, 2003; Vicente-Serrano, 2007; Quiring and Ganesh, 2010; Pasho et al, 2011). Drought monitoring is therefore a complex process, which requires data from all elements of the hydrological system. Blending of this information is necessary for assessing the severity of droughts and its potential impacts. Drought data delivery systems are in general available in many countries from the south-eastern Europe (SEE), but they are not tailored to the needs of users in terms of:

- availability of various drought indicators (meteorological, hydrological and agricultural) to understand better the structural impacts of drought occurrence (Eriyagama et al, 2009);
- availability of meteorological drought indicators, derived from various data sources, to be able to follow the development of drought occurrence in spatial and temporal terms in real time;
- accessibility of drought related data sets and indicators,
- collecting and analysing drought-related information in a timely and systematic manner;
- providing an organizational structure and delivery system that assure information flow between and within the levels of government, institutions and users (Sivakumar et al, 2011).

New technologies are available for developing monitoring and early warning systems based on real-time information to support decision making (Svoboda et al, 2002; Carbone et al, 2008). The competences for collecting meteorological information in Europe correspond to the different states and governmental agencies. A common network of meteorological observatories is therefore not available at the continental scale. In addition, most of the existing meteorological information is not available publicly and on real time. Thus, for undertaking climatic monitoring at supra-national scale, it is often necessary to resort to the publicly available information, provided by the research organizations. These climatic datasets, however, have very low spatial resolution, compared to the datasets available from the national governmental agencies in Europe. Given the large spatial variability of precipitation, it is essential to assess the capability of the low resolution datasets for measuring drought characteristics prior to their utilization for real time monitoring.

In this paper, we analyse the capability of the initial operating capacity (IOC) in drought monitoring, which was developed in the framework of the EuroGEOSS project. The main aim is to assess the ability of the low resolution datasets for quantifying the drought severity in Slovenia. The assessment is based on the comparison of the Standardized Precipitation Index (SPI), calculated from the three different datasets of contrasted resolution. Different characteristics of the SPI series, such as the spatial and temporal variability, are assessed for the different SPI time scales (1, 3, 6 and 12 months). In addition, Pearson correlation between the datasets is explored and the potential of the different datasets for quantifying the drought impacts on agriculture is examined.

2. CAPABILITIES OF THE DROUGHT IOC

Improvement of the data accessing and downloading capabilities is very important achievement in the framework of the EuroGEOSS project. The drought IOC consists of the following main components: the metadata catalogue, the European Drought Observatory (EDO) map viewer and different data download services. It therefore serves the purposes of discovering the data and services related to drought, visualizing and analysing drought data.

The metadata catalogue is the interface to drought-related data and services. It can be seen as the customized interface for search of the data and services, related to drought. The usefulness of the drought metadata has been enhanced for its expert users with a series of implemented optimizations (Latre et al, 2011). The metadata descriptions contain elements foreseen in the INSPIRE Directive as well as additional fields needed by drought researchers to assess the suitability of the datasets for their research. The search for the metadata also takes into consideration drought specific keywords, which have been selected to be a part of the specialized drought vocabulary. The web application for searching and updating the contents of the drought metadata catalogue supports searching based on the location, keywords or text, societal benefit areas categories and temporal parameters.

A series of other tools have been developed to increase the functionality of the drought IOC. These tools are mainly implemented in the EDO Map Viewer, which is a specialized component of the interoperable drought infrastructure for viewing and analysing the drought data. These functionalities include (Hofer, 2012):

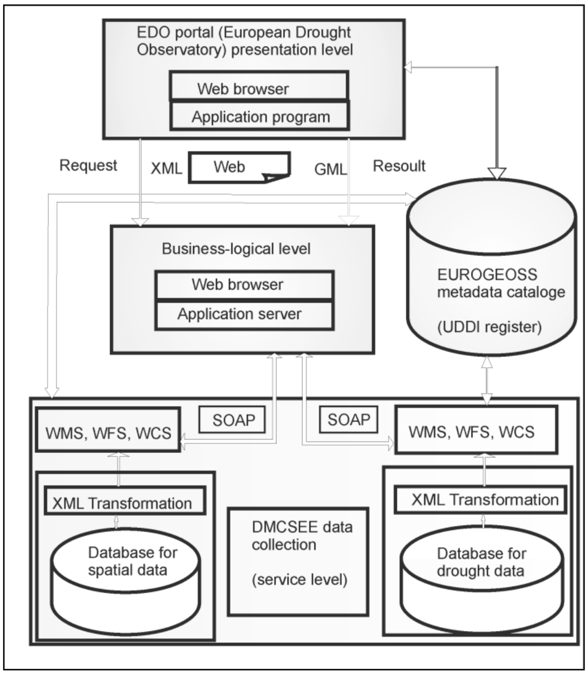
- displaying maps of the given indicator for a selected period in the past;
- the visual comparison of the drought situation as represented by the different drought indices;
- viewing graphs of the time series data;
- data download, making offline analysis possible;
- multilingual support.

2.1. The Interoperability between the Drought Management Centre for South Eastern Europe (DMCSEE) and EDO

The interoperability between the DMCSEE and EDO has been developed in the framework of the EuroGEOSS project. For the interoperability processes, the open source tools and Open Geo-data Interoperability Specifications (OGC) were used. The DMCSEE maps, described by the MapServer software and standard OGC specifications for web services (WMS), were changed into the dynamic presentations and integrated into the EDO. The presentation level, which is the interactive point for the end user, is the most visible part of the interoperability infrastructure. This level forwards requests and relevant parameters to the web server via the HTTP communication protocol, presents the data results to the end user and performs basic operations (Figure).

For the exchange of spatial data in the above described infrastructure, Geography Markup Language (GML), an XML based format for data sharing, was used. The GML is a markup language for geographic data that enables modelling, exchange and storage of the data. It contains various objects and description of geographic features like geometry, coordinate systems, topology, time and units of measurement.

Figure 1: System Architecture of the Interoperable Infrastructure



Both, the EDO and DMCSEE, are registered in the drought catalogue as WMS services to deliver the drought products. Web map services from the EDO and DMCSEE were extended with the time dimension, enabling the selection of the time for the data visualization. The DMCSEE WMS contains the SPI layers for the period after 1951 and is being updated monthly, when the new data becomes available for the calculation of the SPI. This aspect is very important in drought monitoring, since it enables a user to visualize the development of drought in terms of its spatial extent and intensity. The DMCSEE has also implemented the WMS with the high-resolution national data, enabling the visual inspection of the drought indices, calculated based on the national meteorological observatories.

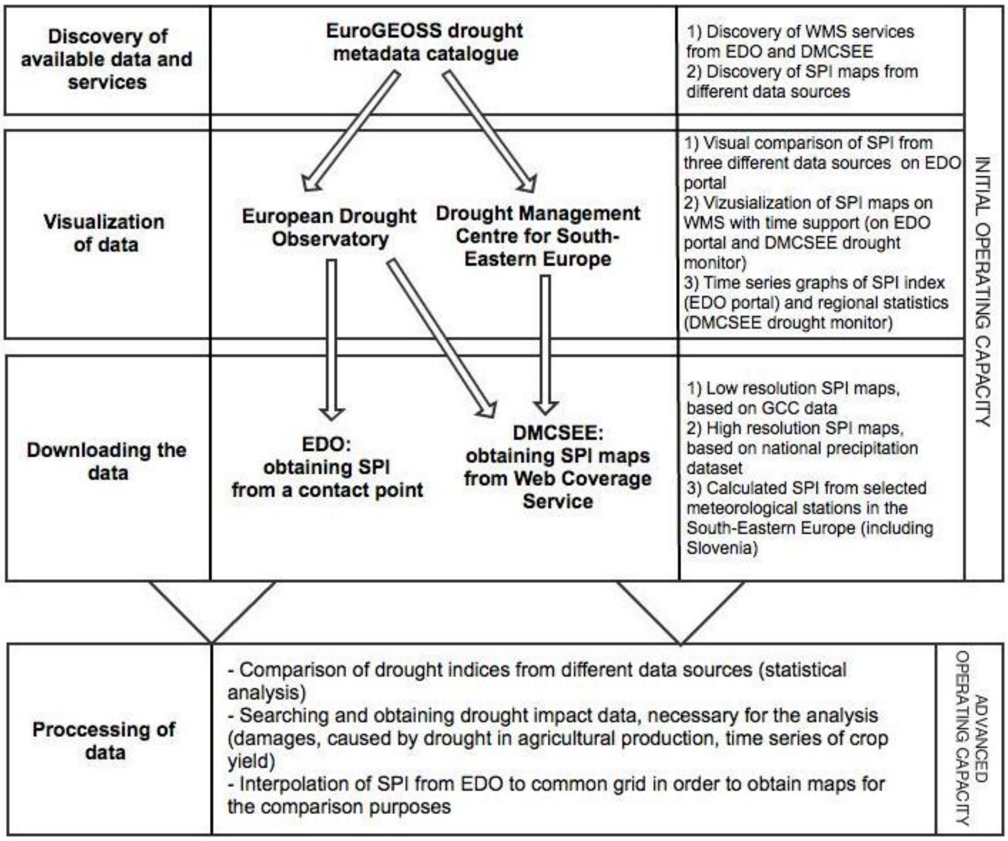
The WMS with high resolution data is integrated into the EDO drought monitor. An automatic updating procedure has been implemented, which ensures that the new maps are uploaded to the DMCSEE MapServer, once they are produced.

3. WORKFLOW OF THE ANALYSIS

Figure 2 represents the workflow of the analysis, from the discovery of necessary data and services, to the data processing. The drought data for the analysis was obtained from the different data providers, which are integrated into the IOC. Available information on the data layers was obtained from the EuroGEOSS Drought Catalogue (Latre et al, 2011). We were able to query for data items from the EuroGEOSS Drought Catalog based on attributes, such as DMCSEE, SPI and Slovenia. Data layers were then visualized through the EDO map viewer (http://edo.jrc.ec.europa.eu/php/index.php?id=74) and the DMCSEE map viewer (http://www.dmcsee.org/GISapp/).

Visual inspection of the SPI from the different data providers was followed by obtaining the data, which was needed for the comparison purposes. The EDO and DMCSEE established the web coverage services, enabling the download of the drought indices in form of the raster layers. We were able to download the geo-referenced images of the low resolution SPI (0.5°) and high-resolution SPI (1 km) from the DMCSEE WCS (Figure 2). The DMCSEE WCS has a time component, allowing the user to select between different time periods to download the SPI data. Data from the EDO was obtained through the contact point on the EDO web page, who delivered us the calculated SPIs for the locations of meteorological stations in SEE from the WMO catalogue. A spatial interpolation had to be performed after obtaining the data in order to make the spatial comparison of the SPI between the different data sources possible. Offline data processing, which includes the comparison of the SPI from different data sources, assessment of the drought impact data and interpolation of the drought indices into common grid, is a part of the advanced operating capacity (AOC).

Figure 2: Workflow of the Analysis; IOC enables the Discovery of the Data and Services, Visualization and Downloading of the Data. Data Processing is a Part of the AOC.



4. STUDY AREA

Slovenia has very complex topography, which is reflected in diverse climate conditions. In the northeast, the continental climate type with the greatest difference between the winter and summer temperatures prevail. In the coastal region, the sub-Mediterranean climate prevails. The effect of the sea on the temperature is visible also up the Soča valley, while a severe Alpine climate is present in the high mountain regions. There is a strong interaction between these three climatic systems across the most of the country. The precipitation varies across the country as well, with over 3500 mm in some western regions and dropping down to 800 mm in the Prekmurje region. Agricultural droughts occur most frequently in the north-eastern and Mediterranean parts of Slovenia. Extreme and long-lasting water deficits for crop growth were reported from these regions. According to climate change studies, these are also the most vulnerable regions to drought occurrence in the future (Ceglar and Kajfež-Bogataj, 2012).

5. DATASETS AND METHODS

5.1. SPI Datasets

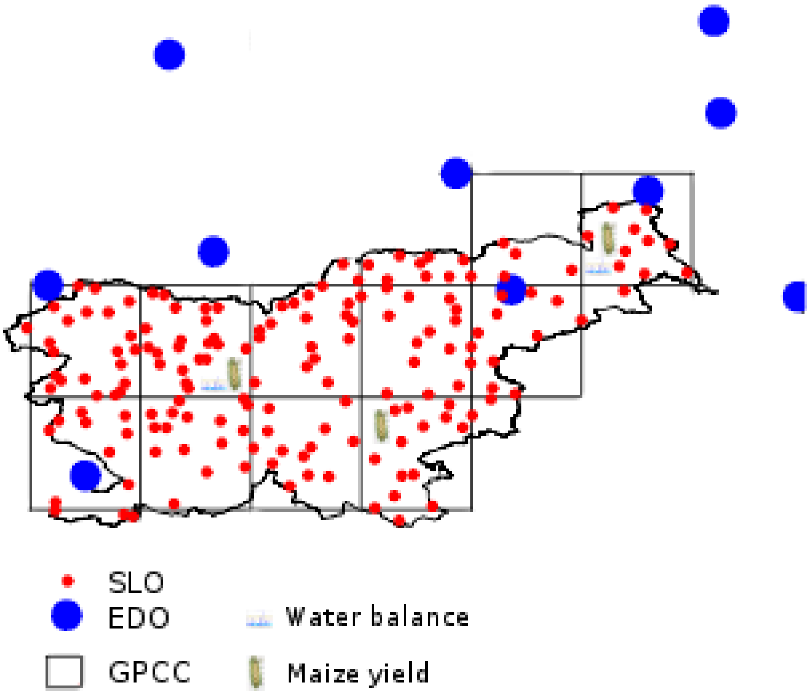
The SPI represents the transformation of the precipitation time series into the standardized normal distribution. The two-parameter gamma distribution was used in our study for fitting precipitation distribution. The maximum likelihood method is used to optimally estimate these parameters; the resulting parameters are then used to find the cumulative probability G(x) of an observed precipitation event for the given month and time scale for the station or grid point in question. In case of zero precipitation, the cumulative probability becomes (Thom, 1966): $H(x)=q+(1-q)G(x)$, where q is the probability of a zero precipitation event. Detailed description of the complete transformation procedure, which was used in our study, can be found in Guttman (1999).

Variable time scale enables the SPI to describe the drought conditions in meteorological, agricultural and hydrological applications. Another important issue that is addressed with the variable time scale is the dynamics of drought; it is capable of determining the onset, duration and intensity of drought. The drought event occurs at any time when the SPI is continuously negative and reaches value -1.0 or less. The event ends when the SPI becomes positive. Each drought event, therefore, has a duration defined by the beginning and the end, whereas intensity increases for each month that the event continues.

The three different SPI datasets for the period 1974-2010 were used for the comparison purposes. Two of them were obtained in the gridded form: the reference high quality dataset on spatial resolution 5 km and the DMCSEE dataset on spatial resolution 0.5°. The high resolution SPI was calculated from the dense network of national meteorological observatories, whereas the low resolution SPI from the Global Precipitation Climatology Centre (GPCC) gridded precipitation data (Rudolf et al, 2010). Both datasets were downloaded using the DMCSEE WCS. The third dataset was obtained from the EDO. It contained the calculated SPI values from the meteorological observatories in the south-eastern Europe, which were found in the World Meteorological Organization catalogue.

The SPI calculations were independent for the reference, EDO and 0.5º gridded series from the GPCC dataset. The calculation of the high-resolution SPI for Slovenia was made in several steps. In the first step, precipitation for the period 1971-2010 was interpolated to 1 km grid, using the universal kriging (Kastelec and Košmelj, 2002). It was followed by the calculation of the SPI for each grid cell. The software for drought indices calculation (Ceglar and Kajfež-Bogataj, 2008), which was developed for the DMCSEE, was used for calculating the SPI values. Precipitation data from the reference period 1981-2010 was used to estimate the parameters of the gamma probability distribution. The same software and reference period were used to calculate the low-resolution SPI from the GPCC dataset. The SPI values, obtained from the EDO, were calculated for the same reference period, as previous datasets (1981-2010). The ordinary kriging (Cressie, 1993) was used to interpolate the obtained SPI values on regular grid with spatial resolution 5 km for the whole south-eastern Europe. In addition, meteorological observatories from the north-eastern part of Italy, Austria and western Hungary were included in the interpolation to reduce errors near Slovenian border (Kastelec and Košmelj, 2002). Only the SPI for Slovenian area was used in the subsequent analysis. The reference SPI dataset was re-gridded to the EDO (5 km) and GPCC (0.5º) resolutions to make the comparison between the different datasets possible (Figure 3).

Figure 3: Spatial Distribution of the Stations used in the Reference (Slovenian), EDO and 0.5º Gridded Pixels from the GPCC Datasets



5.2. Drought Impact Data

Two different environmental data sets have been used to compare the reliability of using the different SPI datasets to identify drought impacts. A water balance data were used on the one hand as a direct indicator of water availability for crop growth whereas a maize yield was used on the other hand as an indirect indicator of the weather conditions during the growing season. Both indicators were measured as well as modelled. Modelled values represent an important estimate of conditions on locations, where the measurements are not available.

An agricultural water balance, used in this study, was calculated using the calibrated water balance model IRRFIB (Matajc, 2001), which is used also operationally in agro-meteorological department of the Environmental Agency of the Republic of Slovenia. The IRRFIB model simulates water consumption by crops during their vegetation season and ripening season, taking into account the soil water characteristics, phenological phases of crops, rooting depth and atmospheric conditions. Since the water balance measurement system has been established only recently (few years ago), modelled values represent important data source for the analysis of the drought conditions in the past, when all meteorological input data are available. Recent evaluation of the IRRFIB model has shown, that the IRRFIB simulations are in general of good quality (Sušnik et al, 2010), but possess very micro-location capability. We have therefore chosen two sites for the comparison, where simulations are in good agreement with the measured data: Ljubljana and Murska Sobota (Figure 3). The calibrated IRRFIB model was used to simulate the water balance for the soil, where maize was grown, for the period after 1971.

Maize yield was used on the other hand as the indirect indicator of the weather conditions during the growing season. Since the data on maize yield are available only for the short time period (around 15 years), modelled values for the period between 1961 and 2008 were used for the comparison purposes. The dynamic crop model WOFOST (Boogaard et al, 1998) was used to simulate the maize yield in the past climate conditions. Measured yield data from the field and observed phenological stages were used to calibrate the crop model in the Bayesian framework (Ceglar et al, 2011). The phenological data and measured yield at the maturity on these locations was obtained from the Agricultural Institute of Slovenia. The maize variety Furio, used in our study, was grown on these locations from 1995 until 2008. In the field experiments during these years the maize was well managed without irrigation, using fertilization and pesticides. Under these circumstances the climate was the major determinant of the yield variability. The maize yield was simulated for the three representative agricultural locations in Slovenia: Ljubljana (central Slovenia), Novo mesto (south-eastern part of Slovenia) and Murska Sobota (north-eastern part of Slovenia) (Figure 3). Unfavourable weather conditions like hail and strong wind, which can damage plants on sub-daily time scale, were not included in the yield simulations. This enabled us to study the impact of drought episodes of different duration and intensity on the maize growth and yield at the end of the growing season. Recent study has shown, that simulations of the maize yield are in general of good quality for the selected locations (Ceglar et al, 2011)

5.3. Statistical Methodology for the Comparison

The comparison between the different datasets was performed using various statistical techniques. We used correlations to determine the relationship between the different datasets as well as the areas of low agreement between the drought datasets. The SPI time series from the three different data sources have been obtained for each grid cell, where maize yield was measured and simulated. Correlations have been calculated between the time series of annual maize yield and monthly time series of SPI on the different time scales. Since the maize is grown in the warm half of the year, only the SPI values, calculated from May (maize sowing) until October (maize ripening) have been used in the calculation.

6. RESULTS WITH DISCUSSION

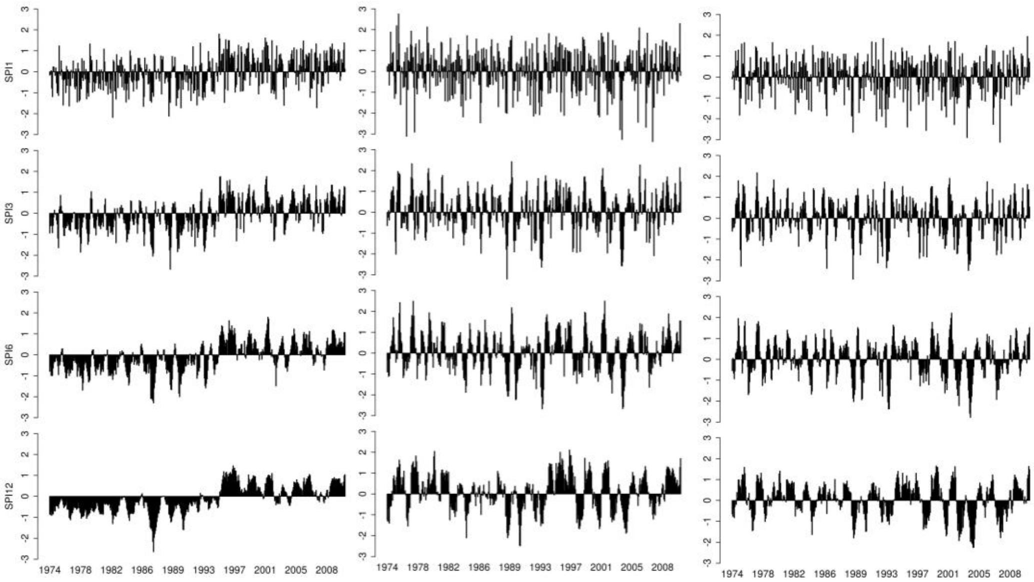
6.1. Comparison of Drought Indices from the Different Datasets and Spatial Resolutions

Figure 4 shows the temporal evolution of the spatial averages of SPI on the 1, 3, 6 and 12 months time scales, using the three different datasets. The main drought episodes recorded in the reference dataset are well identified in the GPCC dataset, especially on the shorter time scales (1, 3 and 6 months). The highest correlation was observed for the 3 and 6 months time scales (0.94), whereas slightly lower correlations for the 1 month (0.92) and 12 months (0.90) time scales. On the other hand, the EDO dataset was not able to identify the main drought episodes, especially on the longer time scales (6 and 12 months). Corresponding correlations were the lowest on the 12 months time scale (0.35) and slightly higher on the 6 months time scale (0.57). Higher correlation was observed on the 1 month and 3 months time scales (0.79 and 0.70, respectively). The EDO time series on the longer time scale show sharp increase of the SPI values in 1995. The SPI values on the 12 months time scale were almost continuously negative until 1995 and almost always positive after that year. This pattern can also be seen on the shorter time scales, but is less pronounced.

This poses a general problem, whether the EDO data series are representative for Slovenia. The lack of representatively arose from the low density of the meteorological observatories, used for the interpolation; only one is located in the study region, several in Austria and one near the border with Italy. Moreover, no observatories from Croatia were used (Figure 1). Given very complex terrain in Slovenia, a network with significantly higher measurements density should be used for the interpolation, especially in the western, northern and south-western part of the country. In the western part of Slovenia, the maximum precipitation is determined by orography and weather dynamics, which also influences the SPI values in that area. It is therefore very important to include the SPI values from different altitudes if we want to obtain representative results. There are only three observatories included in the interpolation procedure in the area, where the most complex terrain prevails, leading to unrealistic representation of the spatial SPI variability. The spatial variability of the SPI values therefore cannot be realistically captured with the low station density, like in the EDO.

In addition, data quality issues were identified in the EDO time series. Visual inspection of the SPI time series for observatories near Slovenia revealed a shift in time series, which cannot be attributed to natural climate variability. The standard normal homogeneity test (Alexandersson, 1986; Steffensen, 1996; Alexandersson and Moberg, 1997) was therefore applied to the SPI time series on the monthly time scale to detect possible inhomogeneities. Several time series from different meteorological observatories were analysed: Trieste, Klagenfurt, Graz, Szombathely, Szentogothart and Nagykanizsa. The critical t-value on the 95% confidence level was exceeded in Klagenfurt, Graz, Szombathely and Nagykanisza. The shift point was detected in 1995 for Klagenfurt and Graz, whereas in 1981 and 1980 for Szombathely and Nagykanisza, respectively. The shift point in 1995 is clearly visible also in spatially averaged time series of the SPI on the different time scales (Figure 4). This clearly indicates that the precipitation time series, used to calculate the SPI, were not homogeneous. Moreover, the precipitation time series should be checked for large gaps of missing data, which make the SPI calculation difficult or even impossible. The results of the comparison between the reference and EDO datasets are omitted in the rest of the results due to identified inhomogeneities in the EDO time series.

Figure 4: Spatial Averages for the 1, 3, 6 and 12 Months SPI for Slovenia, calculated from the EDO (left), GPCC (middle) and Reference (right) Datasets. Spatial Averages have been calculated from the 5 km Resolution (EDO), 50 km Resolution (GPCC) and 1 km Resolution (reference) Datasets.

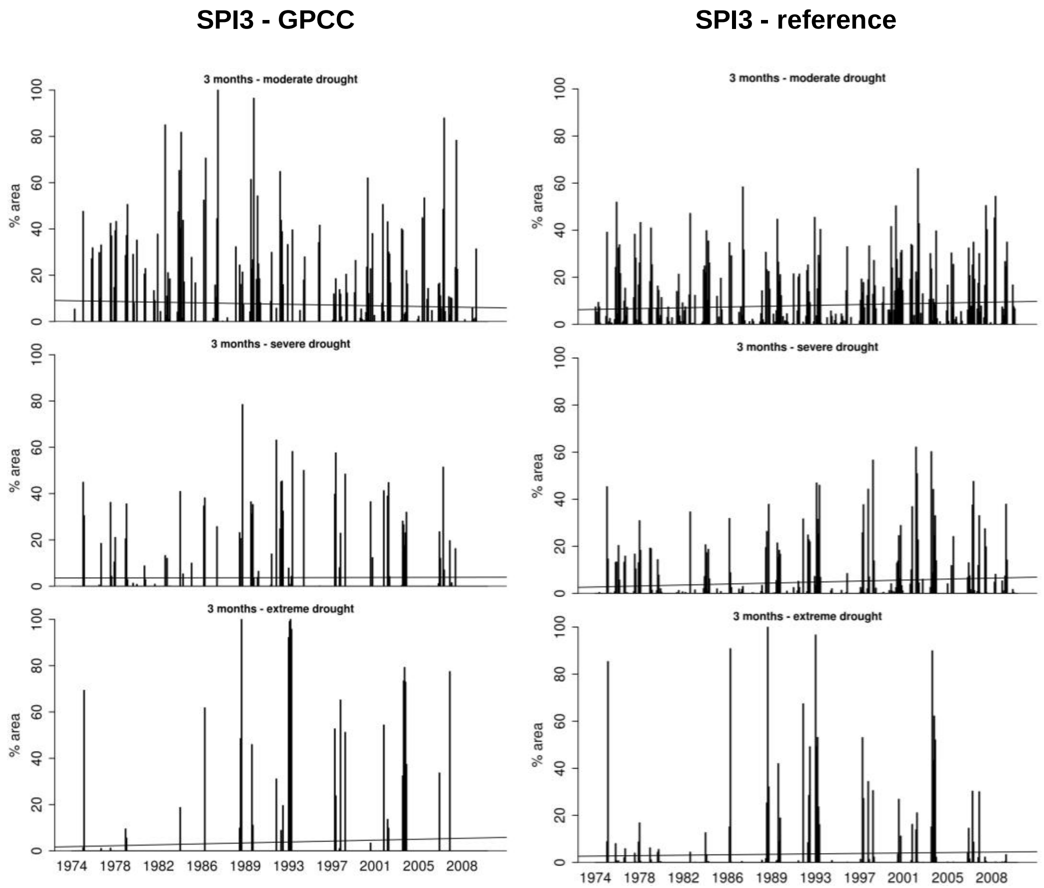


The average drought magnitude and the length of the drought events were quite similar in the reference and GPCC datasets, especially when comparing the SPI on the shorter time scales (Figure 4). On the 12 months time scale, drought magnitude and length, recorded from the GPCC data, were slightly underestimated. The average length of the drought events on the 12-months time scale was 13.3 months for Slovenian dataset and 12.1 months for the GPCC dataset. In addition, the evolution of the surface area, affected by droughts, has been estimated from the two datasets. For this purpose, three different thresholds have been used: SPI=-2 (representing extreme drought events), SPI=-1.5 (representing severe drought events) and SPI=-1 (representing moderate drought events). Figure 5 shows the evolution of the surface area, affected by droughts on the 3 and 12 months time scales. The SPI, calculated from the GPCC dataset, tends to realistically capture the surface area affected by droughts, especially on the 3 months time scale. Better agreement can be found for severe and extreme drought events, whereas the area affected by moderate drought events tends to be overestimated in the GPCC dataset. Similar conclusions can be found for the 12 months time scale. This result is expected, since moderate drought events occur more frequently than severe and extreme drought events. Slightly worse agreement can be observed between the drought affected areas on the 12 months time scale, when comparing the SPI from the GPCC and reference datasets. The largest differences occur in the case of moderate droughts.

Positive trends for the areas, affected by severe and extreme droughts, were recorded from the reference dataset, but not from the GPCC dataset.

Spatial variability in the agreement of the SPI values was analysed as well. Figure 6 shows correlations between the GPCC SPIs and the reference SPIs, aggregated to 0.5° spatial resolution. The correlations were higher than 0.5 on all time scales. The lowest correlation can be observed for the SPI on the 12 months time scale, whereas the highest for the SPI on the 3-months time scale. In general, the correlation was the highest in the eastern and southern parts of Slovenia (for all time scales), whereas the lowest can be found on the north-western part of Slovenia. This result is expected, since the north-western part has very complex topography, resulting in many local climate characteristics, which cannot be resolved on such a coarse spatial resolution.

Figure 5: The Evolution of the Surface Area affected by Droughts on the 3 and 12 Months Time Scales



SPI12 - GPCC **SPI12 - reference**

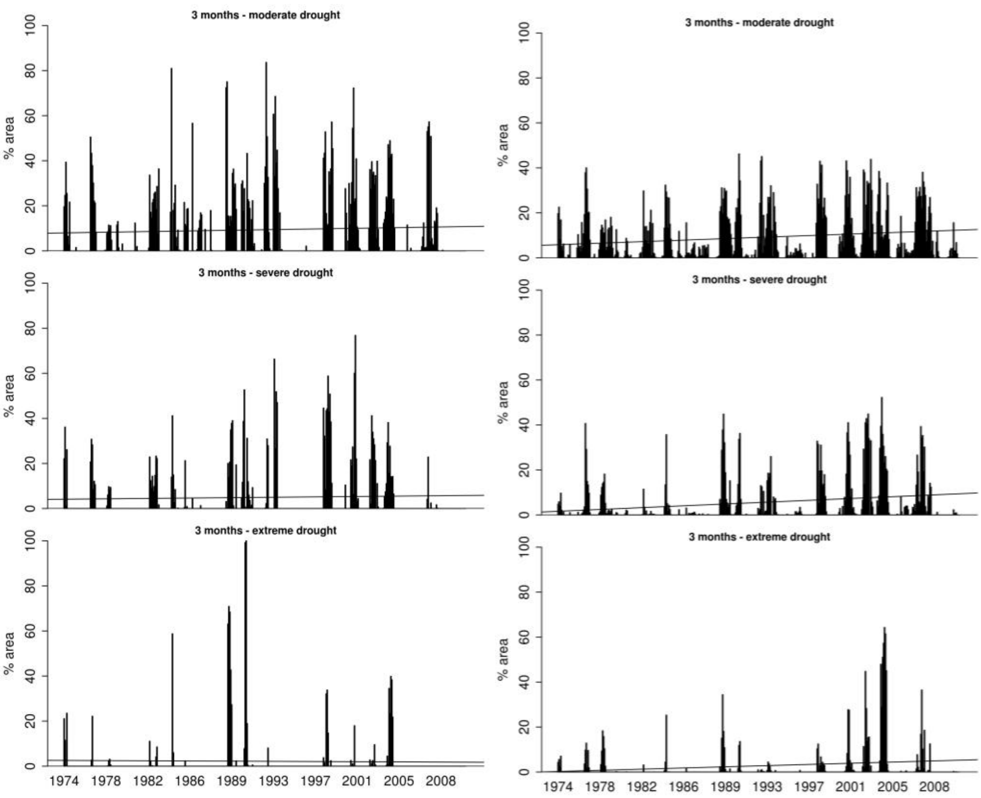
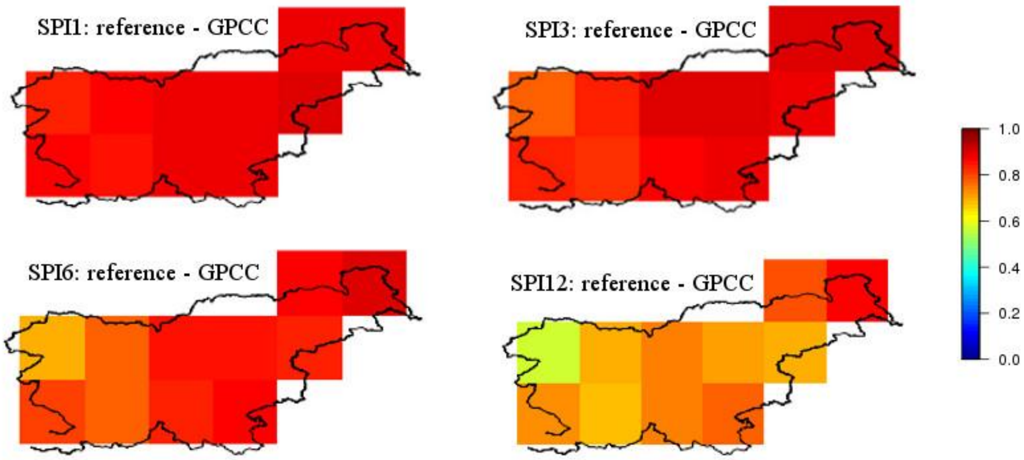


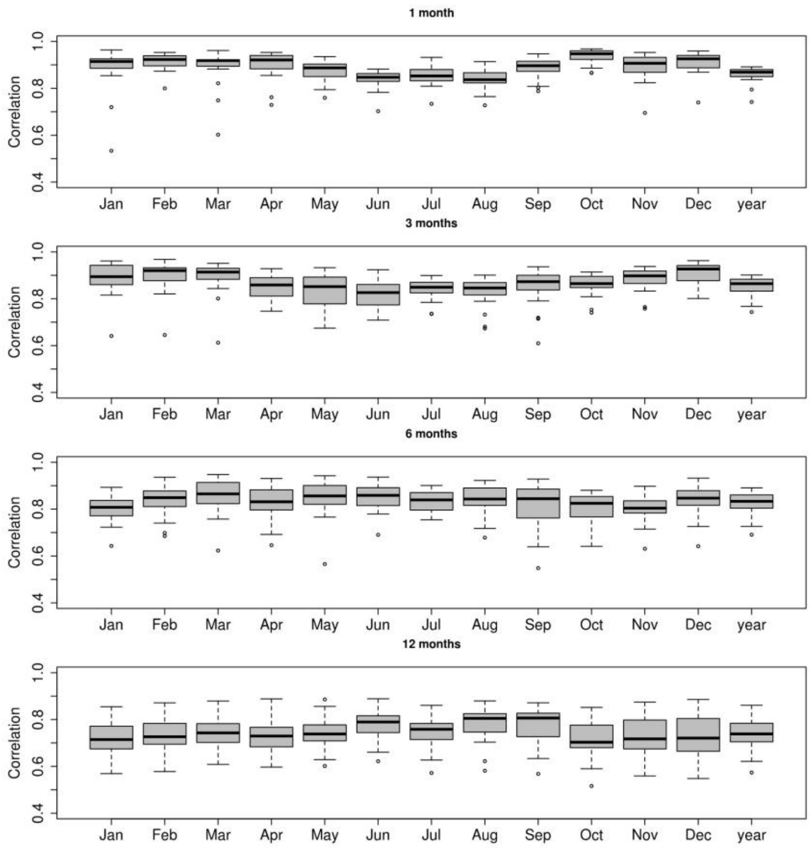
Figure 6: Correlations between the Reference SPI and SPI from the GPCC Dataset on the Different Time Scales



Given the low resolution of the GPCC data, close agreement with the reference SPI can be considered. The GPCC data offers a reliable quantification of drought severity conditions, which can also be observed for monthly correlations (Figure 7). Higher correlations on the 1 and 3 months time scales can be observed in the cold half of the year with the highest correlation occurring in October. In autumn, precipitation in Slovenia is usually strongly related to the Mediterranean cyclogenesis, which brings humid air masses with south-westerly winds from the Mediterranean. In summer, convective precipitation regime with intense local character prevails. This explains lower correlations during the summer months, when coarse resolution data are not able to realistically describe precipitation events, which are influenced by local characteristics. Nevertheless, the correlations tend to be higher than 0.8 also in the summer months. For the longer time scales (6 and 12 months) higher correlations can be observed in the warm half of the year. Stronger spatial variability in the correlations was found in the winter than in summer. The reason can be the aggregation of precipitation data on longer time scales (6 and 12 months). Since precipitation amount in the winter is generally the lowest, precipitation events in the summer and autumn strongly influence the SPI values in the winter, resulting in higher spatial variability.

According to the analysis of the results given above, we can confirm quite good reliability of the low resolution GPCC SPI to reproduce the drought variability in Slovenia. The EDO dataset, on the other hand, exhibits problems at reproducing realistic SPI values due to inhomogeneities in the input data. Its applicability in Slovenia is therefore very limited. Despite lower spatial resolution, better reliability of the GPCC dataset is expected, since higher station density has been used to interpolate precipitation. Between 10 and 15 stations were used for interpolation in the north-western part of Slovenia, where the highest variability of topography can be found, whereas approximately 80 stations were used in other parts of the country. In addition, the station data have been quality and homogeneity controlled prior to the interpolation (Rudolf et al, 2010).

Figure 7: Box-Plot of Correlations between Reference SPI and GPCC.SPI at the 1, 3, 6 and 12 Months Time Scales. Each Bar summarizes the Correlations for the Complete Set of 5 km and 0.5° Grid for the Corresponding Month and Time Scale. Box "13" corresponds to the Correlations from the Complete Series without distinguishing between Months.



6.2. Assessment of the Capability of the Different Drought Datasets to monitor Impacts on the Maize Yield and Soil Water Balance

In this section, the performance of the two different drought datasets to identify the droughts impacts on maize yield (Zea Mays L.) and soil water balance is shown. For this purpose, maize yield has been simulated on the three different locations in Slovenia (central, south-eastern and north-western Slovenia), which are representative for a wider agricultural area in their surroundings. The maize yield at the end of the growing season is a good indicator of the weather conditions during the growing season. Dry conditions lead to stress, which can result in significant yield reduction at the end of the growing season. The simulated maize yield has been standardized prior to calculating the correlations. The Spearman rank correlation coefficient has been estimated, since the standardized maize yield usually does not follow the normal distribution.

Figure 8 shows the results of the correlation analysis for the three different sites. The strongest correlation between the SPI and maize yield is recorded from the reference SPI dataset for all study locations. The correlations, obtained from the GPCC data, were only slightly lower. This is surprising, since especially in Ljubljana and Novo mesto, the local terrain characteristics significantly influence climate properties, which cannot be resolved on coarse grid resolution, such as the one from the GPCC. Moreover, the response was very similar on all time scales. The highest correlation can be observed between the yield and SPI on the 3 months time scale. There is a slight difference in the timing of the highest correlation. The GPCC dataset produced the highest correlations in July, whereas the reference dataset in August. Nevertheless, the differences are very small. The lowest correlations from May until August were observed for the SPI on the 12 months time scale in both datasets. Both datasets imply that maize yield is influenced by the drought conditions in July and August, when maize is in the growth stage, which is the most sensitive to unfavourable meteorological conditions (Ceglar and Kajfež-Bogataj, 2012).

In the second part, the water balance has been estimated for the soils in Ljubljana and Murska Sobota, where the maize was grown. The agricultural water balance is a direct indicator of a drought stress for crops. The drought stress occurs in situations, where crop evapotransipration is less than potential evapotranspiration. Crop evapotranspiration is related to the water availability in the root zone. Water balance is measured and calculated on a daily basis. For the comparison purposes, these measurements and estimates have been aggregated to the monthly values, which represent the monthly sums of the daily soil water deficit (the soil water deficit is defined as the amount of water, necessary to reach the field capacity). After summing the deficits, the monthly aggregates have been standardized in order to be comparable to the SPI time series. The SPI time series from the different data sources have been compared with the monthly aggregates of the water deficits for months between May and September.

The highest correlation has been obtained for the SPI on the monthly time scale, especially in May, June and July (Figure 8). Correlations in August and September were similar for the SPI on the monthly and 3 months time scales in

Ljubljana. In Murska Sobota, the SPI on the 3 months time scale exhibited the highest correlation in September. Similar response can be observed for the reference and GPCC datasets, although the fine resolution dataset produced slightly higher correlations (negative), especially in the spring and early summer. The result is expected, because the majority of precipitation during that period is a consequence of convective activity. The GPCC dataset reproduces quite well the differences in the response to different time scales of climatic droughts. The differences in the monthly correlation curves are very small, which supports an application of the GPCC dataset also on the regional and local level with the purpose of monitoring the agricultural drought.

Figure 7: Correlation between the Standardized Maize Yield and SPI on the 1, 3, 6 and 12 Months Time Scales, calculated from the two Different Datasets (Slovenian and GPCC) for Ljubljana (left), Murska Sobota (middle) and Novo mesto (right)

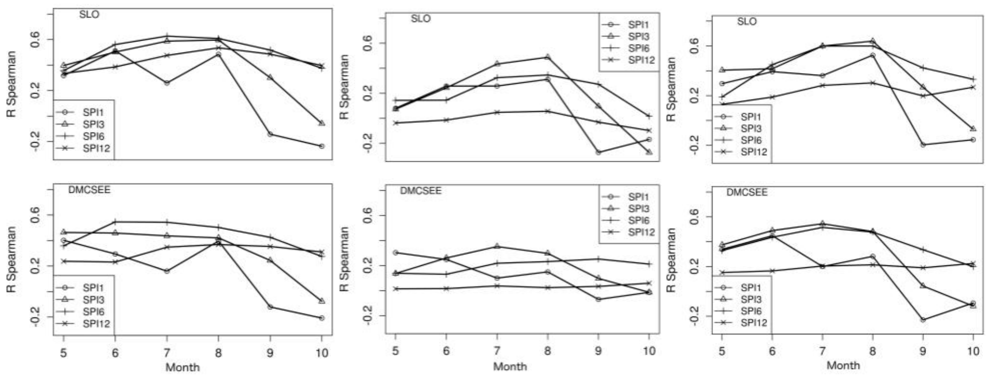
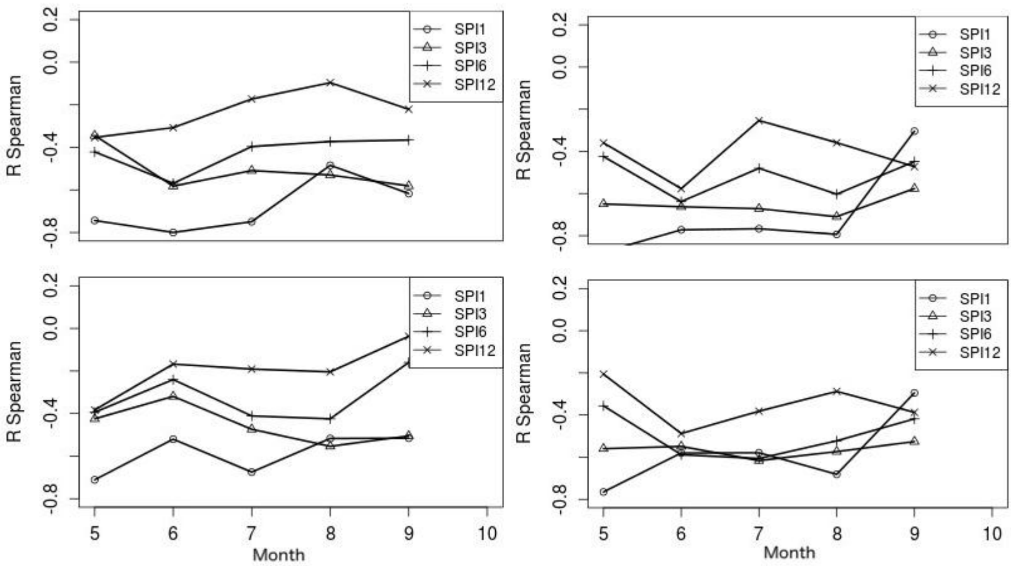


Figure 8: Correlation between the Standardized Soil Water Deficits and SPI on the 1, 3, 6 and 12 Months Time Scales, calculated from the Two Different Datasets (Slovenian and GPCC)



7. CONCLUSIONS

The implemented model of the integrated drought monitoring system provides the solution on both, technical and political level, for the development of the AOC in the field of drought monitoring. IOC, developed within the EuroGEOSS framework, was used for comparison of the drought indicators, derived from the different databases, and for assessment of the agricultural drought in Slovenia. Comparison of the drought indices required a large amount of data for the offline analysis. The download of data is not sufficiently well supported yet, which is mainly a problem, arising from political and legal reasons.

There is a lack of the drought data from the countries from SEE. The drought impact data play important role in the analysis of the impact of climatic droughts on hydrological systems, agriculture and biodiversity. The lack of the impact data and their high institutional diversity in SEE make it difficult to perform the analysis, which is a part of the AOC. The EuroGEOSS has provided a framework for integration of drought relevant data into the interoperable platform, which is necessary for the AOC. The analysis in this use case scenario revealed some functionalities that should be a part of the AOC in order to tailor the web processing services to the needs of various users in the drought community. We have shown that the SPI can be used to monitor the agricultural drought in Slovenia, also when using the low resolution GPCC data. The meteorological drought index has been compared to the maize yield and soil water balance, which can be used to quantify the impact of the drought on the crop production. It has been shown, that SPI on the 3 months time scale for July and August is a good indicator for quantifying the impact of the meteorological drought on the maize yield at the harvest. Similar study has been performed for the Ebro river basin, where the capability of the SPI was assessed to quantify the impact of the meteorological drought on the surface water hydrology and the tree growth (Morán-Tejeda et al, 2012). Important conclusion that can be drawn from our study and the study from Morán-Tejeda et al. (2012) is that the meteorological drought influences the agricultural production, surface hydrology and tree growth on different time scales, which depend on the bio-physical characteristics of the environment (soil type, crop characteristics, geological characteristics, …). The AOC should provide a framework to identify these time scales, which are usually spatially highly variable. The above results have illustrated the capacity of the drought products, generated in the frame of the European drought monitoring systems, to quantify accurately the severity of the droughts, their temporal variability and trends and to identify the drought impacts in agriculture. Better results are obtained in terms of quantifying accurately the severity of droughts and determining the drought duration, intensity, magnitude and spatial extent, when using the high resolution climate datasets. Higher resolution climate datasets are preferable to identify better the impacts of drought and to determine differences in the drought vulnerability.

The low resolution dataset from the GPCC, analysed in this study, can reproduce quite well the general drought temporal variability, but mainly at the short time scales. Similar conclusions were obtained, when comparing the low-resolution EDO, low-resolution CRU (Climate Research Unit) and high-resolution national datasets for identifying drought conditions over the Ebro basin in Spain (Vicente-Serrano et al, 2011). In addition, although the drought impacts and the drought vulnerability are better identified using the drought information at the high spatial resolution, the low resolution dataset from the GPCC provides reliable outputs in terms of knowing the impacts on the agricultural production in Slovenia. Low degree of agreement between the reference SPI and SPI from the EDO emphasizes the importance of having a denser net of the meteorological stations and quality controlled data to produce the maps on the sub-continental as well as the continental scale.

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