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Multi-Disciplinary Forest Fire Danger Assessment in Europe: The Potential to Integrate Long-Term Drought Information[*]

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Abstract

A key motivation for multi-disciplinary collaborations is the inclusion of data and knowledge from contributing disciplines for the further development of existing models. The objective of this research is to evaluate the potential of using drought information from the European Drought Observatory (EDO) to complement the forest fire danger assessment of the European Forest Fire Information System (EFFIS). Drought conditions are provided through the Standardized Precipitation Index (SPI), which is a spatially invariant and probabilistic year-round index based on precipitation alone. For verifying the hypothesis that drought information can improve the danger assessment of forest fires, we statistically analyse the correspondence between multi-timescale drought condition information with the incidence of forest fires. Within this paper, we perform a detailed comparative analysis of the SPI frequencies for burnt areas with the respective SPI frequencies for the total study area during the same period. The research is carried out in the Iberian Peninsula for the reference year 2009, using the burnt areas mapped by the EFFIS Rapid Damage Assessment. The results clearly show that the frequencies of burnt areas in Iberian Peninsula relate to the regions with abnormal 24-month accumulated precipitation totals, as

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mapped by the SPI. This suggests that the long-term lack of water contributes to vegetation dryness in the region and thereby increases its risk of fire danger. The added value of including drought information in the fire danger assessment lies in particular outside the forest fire season, when it provides complementary information on areas under risk that are not necessarily marked with a high fire risk following the risk assessment of EFFIS. Based on the results of the study, we suggest an operational integration of drought information coming from EDO into EFFIS using the existing web service infrastructure.

Keywords: forest fire danger assessment, drought, web service infrastructure, multi-disciplinary research

1. INTRODUCTION

Al Gore (1998) formulated the vision of a Digital Earth, which efficiently communicates information on virtually any subject to a broad audience using space as the organizing principle. This vision has partly become true with developments such as Google Earth and a series of initiatives that promote the exchange of spatial data (Craglia et al, 2008): e.g. the Infrastructure for Spatial Information in the European Community (INSPIRE) (INSPIRE, 2011); the Global Earth Observation System of Systems (GEOSS) aims at interlinking Earth observation data and resources across nine societal benefit areas (SBAs) globally (GEO, 2011).

McInerney et al (2012, last paragraph) point out that it is timely to go beyond making data available across disciplines and start using them for scientific purposes: “[w]hile the access to these data is of fundamental importance, their value is increased when they are used within GII [Geographic Information Infrastructures] for geo-processing or modeling to answer interdisciplinary scientific questions and support decision making”. This is a key objective of the European Commission funded EuroGEOSS project, i.e. the European contribution to GEOSS, that aims at enabling scientific interdisciplinary collaboration across thematic areas by making their data and models discoverable, accessible and usable through the EuroGEOSS Discovery Broker (Craglia et al, 2012). EuroGEOSS focuses on three thematic areas, namely forestry, drought and biodiversity. Each of these thematic areas established a web service-based infrastructure providing map viewer, metadata catalogue, and web processing capabilities that are registered in the Discovery Broker.

The forest thematic area focuses on two principal activities. The first relates to the provision and maintenance of pan-European forest resource information, which is done in the European Forest Fire Information System (EFFIS)[1]. The second activity concerns the protection of forests from wildfires in Europe. The key objective of the latter activity is to reduce the impact and number of forest fires on society and environment by closely monitoring fire danger during the fire season and also monitoring active fires. Fire events occur mostly in the EU Mediterranean countries from May through to late September, but in 2011 the fire season was more prolonged and large fires also occurred in northern and central Europe. Forest fires have serious impacts on the environment, habitats, air quality and emissions as well as leading to soil erosion.

Drought is a meteorological hazard that is a normal part of climate that affects all regions of the world. As a temporal and recurring event, it is defined as the lack of precipitation over a certain period of time relative to some predetermined threshold, which may or may not have adverse consequences to ecosystems and populations (Wilhite and Glantz, 1985). Under the auspices of the EuroGEOSS project, multi-scale pan-European drought indices, which describe drought conditions, are collected and processed by the European Drought Observatory (EDO)[2] (Vogt et al, 2011). One key index is thereby the Standardized Precipitation Index (SPI), which describes the deviation of precipitation from long-term mean conditions for accumulation timescales ranging typically from 1 to 24 months. The specific tasks of the EDO are drought detection, monitoring, forecasting and assessment. Within the context of the EuroGEOSS project, a Web-based service infrastructure was set up that connects drought data providers acting at local, regional and continental scales in Europe. The idea behind this infrastructure was to have on the one hand continental drought data providing an overview of the drought situation in Europe and on the other hand linkages to regional and local drought data for more spatially explicit information on droughts.

The linkage between forest fires and drought conditions has previously been studied and approved (c.f. Swetnam, 2001; Reinhard et al, 2005; Xiao and Zhuang, 2007; Fernandes et al, 2011). The forest fire danger rises with increased dryness of the vegetation and dead fuel moisture. A key difference in precipitation data currently used in the Forest Fire Danger forecast and in the SPI is the time scale on which a lack of precipitation is assessed. The forest fire danger assessment considers precipitation of the previous 24 hours whereas the SPI looks at accumulation timescales typically starting from one month. The specific objectives of this research are:

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[1] http://effis.jrc.ec.europa.eu/
[2] http://edo.jrc.ec.europa.eu/

1. To demonstrate the potential of using long-term drought information as a means of complementing or improving the fire danger forecast produced by EFFIS;
2. To determine the usefulness of SPI data on various timescales as an explanatory variable within the EFFIS Fire Danger Forecast;
3. To demonstrate that the integration of multi-disciplinary data has the potential to provide a Fire Danger forecast which would alert fire fighting authorities not only to areas which are susceptible to fires as a result of recent meteorological conditions (e.g. 1 week max) but additionally to areas experiencing long-term drought stress.

The research is carried out in the Iberian Peninsula, for the year of 2009 by analysing the locations of burnt forest areas in terms of their monthly drought conditions. The study differs from related studies in using just one specific drought index – the SPI – computed for several precipitation accumulation timescales and for all the year under investigation, rather than the fire season only.

2. MATERIALS AND METHODS

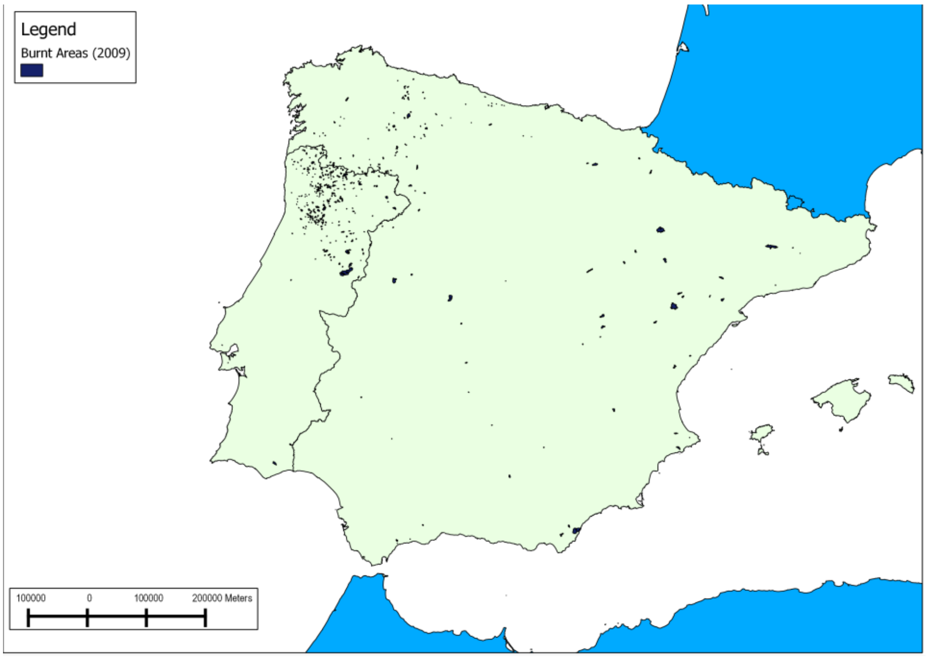
This section introduces the study area, data used to assess the correspondence between forest fires locations and drought conditions, and the methodology for pursuing this study.

2.1. Study Area

The analysis presented in this paper was carried out in the Iberian Peninsula (Fig. 1), which has a Mediterranean climate and is a region prone to forest fires and drought (Gouveia et al, 2009; Caetano et al, 2004; Vicente-Serrano et al, 2004). High temperatures and almost a total absence of precipitation during the summer are responsible for a period of plant stress, when the moisture of plants decreases dramatically and consequently their degree of flammability increases (Caetano et al, 2004). The period between 1st July and 30th September is considered as the forest fire season in this region (MINADERP, 2011). Indeed, during the summer months, the outbreak of forest fires is high and mainly due to high temperatures and the lack of precipitation in the area. During the autumn, after summer dryness and dormancy, the yearly life cycle of plants starts anew and forest fires are expected to be less frequent.

In recent years, the Iberian Peninsula had a high incidence of forest fires, leading to some of the highest percentages of burnt forest in Europe. For example, the total burnt area in Portugal and Spain was over 450.000 ha in 2003, which is equivalent to almost 8% of the Portuguese forest area being affected by forest fires during that year (Merino-de-Miguel et al, 2005). As a consequence of socioeconomic changes that have been taking place in the rural areas of the Iberian peninsula, agricultural land has been progressively abandoned and replaced by unmanaged natural vegetation, which has resulted in an increase in the amount of biomass available for burning (Carrão et al, 2003).

Figure 1: Map Showing the Iberian Peninsula together with Burnt Areas of 2009



For testing and implementing the relation between burnt areas and drought conditions, this study area is appropriate for the following reasons:

1. The high likelihood of experiencing forest fires during the fire season considering that it has also been severely affected by forest fires in the past;
2. The diversity of forest species and terrain characteristics;
3. The increase of forest fires in 2009, as compared to preceding years especially in Portugal (Schmuck et al, 2010), which indicates the importance of improved forest fire danger assessments for that region.

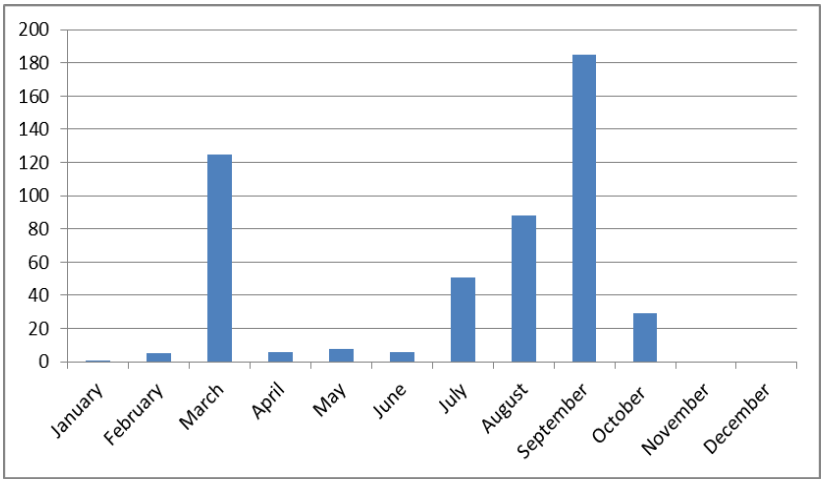
2.2. Materials

This study builds upon three main data sets: the burnt areas mapped by the EFFIS Rapid Damage Assessment for the year 2009 in the Iberian Peninsula, the EFFIS Fire Weather Index (FWI) and the Standardized Precipitation Index (SPI). These data sets are each described in turn.

2.2.1. Burnt Areas of 2009

During the fire season, EFFIS fire experts monitor forest fire events at a pan-European scale. This process involves the detection of fire events from the Moderate Resolution Imaging Spectroradiometer (MODIS) Hot Spots data as well as geo-coded fire news information. When a fire is detected, its location and extent are digitised based on the interpretation of MODIS satellite imagery with a ground sampling distance of 250-m. This results in a product called the Rapid Damage Assessment (RDA), which contains all fires greater than 50 ha. The number of forest fires occurring in 2009 by month is presented in Figure 2.

Figure 2: Number of Forest Fire Occurrences per Month for 2009 (Y-Axis: Number of Forest Fires; X-Axis: Month)



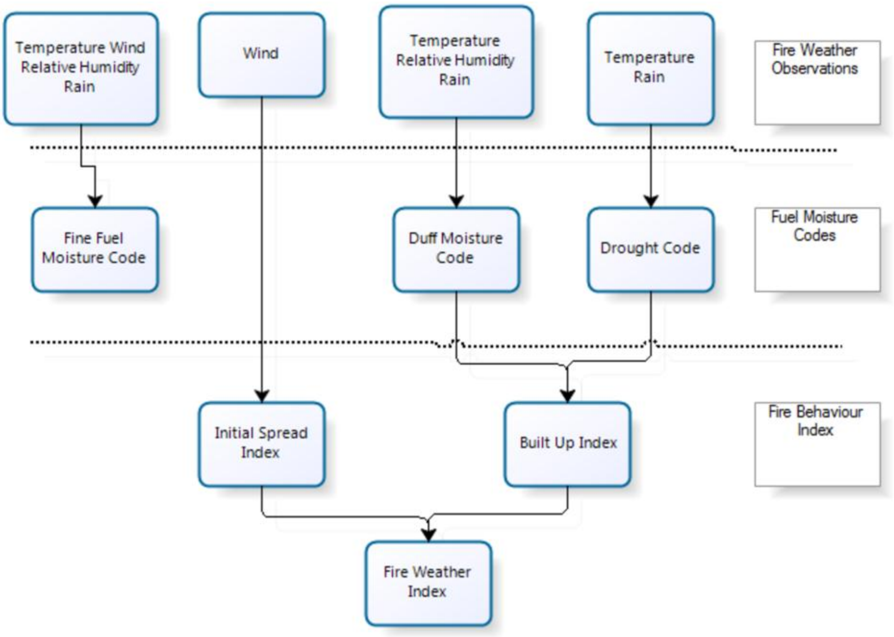
2.2.2. Fire Weather Index and Fire Danger Levels

Fire Danger forecasts are generally computed using meteorological and topographic variables at a national or continental scale. Numerous models have been developed for different regions of the world, with the most notable being the Australian McArthur Forest Fire Danger Rating System (McArthur, 1966) and the Canadian Fire Weather Index (FWI) (van Wagner, 1987). The latter index was adapted to European conditions and is used operationally within EFFIS (Camia et al, 2006).

The FWI is re-calculated on a daily basis using meteorological data from Meteo France and DWD (Deutscher Wetterdienst; German Meteorological Service) at midday. The meteorological observations used within the model are temperature, relative humidity, wind force and accumulated rainfall from the previous 24 hours. These data are used to produce a fire danger forecast for the following six days that is classified into 6 classes (very low, low, medium, high, very high and extreme). These risk classes are referred to as Fire Danger Levels.

The FWI is a composite index that includes a drought code, duff moisture code, fine fuel moisture code, initial spread index and built up index. This drought code provides information on the wetness of the vegetation derived from the accumulated precipitation of the previous 24 hours. Figure 3 presents the inputs and outputs of the FWI model and includes the fuel moistures codes and fire behaviour indices.

Figure 3: Calculation and Components of FWI



2.2.3. Standardized Precipitation Index

Drought periods are assessed through drought indices, which measure the lack of precipitation or assess impacts of reduced precipitation on vegetation, soil moisture, groundwater etc. Such indices are the foundation of drought monitoring as done by the European Drought Observatory (EDO) (Vogt et al, 2011).

In this research the Standardized Precipitation Index (SPI) is used to evaluate monthly drought conditions in the Iberian Peninsula during the year of 2009. The Standardized Precipitation Index (SPI) was proposed by McKee et al (1993) and its main purpose is to measure the intensity of monthly accumulated rainfall deviations to some local long-term average precipitation regime. Precipitation frequencies at each month can be simultaneously computed for different accumulation periods, or timescales, typically 1-, 3-, 6-, 9-, 12- and 24-months. Short accumulation timescales are useful for monitoring drought impacts on agricultural yields, while long accumulation timescales are important mainly for assessing impacts on reservoirs levels and groundwater supplies (Hayes et al, 1999). Although the SPI was initially proposed for measuring imbalances in water resources up to 48 months, Agnew (2000) states that drought just occurs when rainfall is abnormally below average for periods up to 2 years; longer abnormal periods indicate an aridization process brought about by climate change and should not be considered as drought.

The SPI is a simple meteorological probabilistic year-round index that is derived for any accumulation timescale from a cumulative distribution function (CDF) fitted to some long-term reference precipitation time-series alone. Monthly drought intensity for a specific timescale is categorized according to the cumulative probability value estimated from the CDF for the precipitation accumulated during the correspondent time period (Table 1, Mckee et al, 1993). In practice, if the cumulative probability value estimated for the total precipitation is around the local reference median precipitation, then the water supply conditions are normal; cumulative probabilities greater than the median suggest surplus water supply conditions, while smaller cumulative probabilities indicate dry periods.

Table 1: Drought Classification Categories for SPI Values

SPI Value	***Class***	***Cumulative Probability***
SPI ≥ 2.00	*Extreme wet*	*0.977 – 1.000*
1.50 < SPI ≤ 2.00	*Severe wet*	*0.933 – 0.977*
1.00 < SPI ≤ 1.50	*Moderate wet*	*0.841 – 0.933*
-1.00 < SPI ≤ 1.00	*Near normal*	*0.159 – 0.841*
-1.50 < SPI ≤ -1.00	*Moderate dry*	*0.067 – 0.159*
-2.00 < SPI ≤ -1.50	*Severe dry*	*0.023 – 0.067*
SPI < -2.00	*Extreme dry*	*0.000 – 0.023*

Source: Mckee et al, 1993

The precipitation frequencies for each month and timescale were derived from the E-OBS dataset developed in the framework of the Framework Program-6 project ENSEMBLES (Haylock et al, 2008). In short, E-OBS is a European land-only daily gridded precipitation observational dataset produced at the spatial resolution of 25 x 25 km and covering the period from 1st January 1950 to 30th

June 2011. For each pixel in the study area and different precipitation accumulation timescales (1-, 3-, 6-, 9-, 12- and 24-months), a cumulative distribution function (CDF) was estimated for each month by inverting the gamma probability density function (PDF) fitted to the respective long-term reference precipitation frequency. Gamma parameters were fitted to the data using the L-moments estimators (Hosking, 1990). Since the gamma distribution is bounded on the left at zero, it is not defined for zero precipitation. If the long-term reference precipitation frequency includes observations of zero precipitation, then a mixed distribution is used that takes account of the probability of zero precipitation. As reference, we used a 30-year monthly precipitation record, from January 1961 to December 1990, in accordance with the recommendations of the World Meteorological Organization (WMO) (WMO, 2011).

The definition of drought is always a relative statement of how much the current precipitation differs from the expected average precipitation for the region. In the Iberian Peninsula during the summer months there is hardly any expected precipitation due to its climatic characteristics. Thus, it is expected that the SPI computed for short accumulation periods (1-, 3-months) will not show a drought event, because the meteorological conditions during summer do not indicate a lack in precipitation.

2.3. Methodology

The drought code of the FWI is based on the total precipitation accumulated during the preceding 24 hours; it is, therefore, an absolute and short-term measure. The SPI used in this study assesses the deviation of precipitation values for accumulation periods of one to 24 months and provides more long-term drought information. The structural difference of drought information currently included in the FWI and the information provided by the SPI, gives rise to this study for evaluating the usefulness of including the SPI in the forest fire danger assessment of EFFIS.

The specific tasks of this analysis include:

1. The evaluation of the relationship between forest fire occurrence and the prevailing drought conditions at the time of their occurrence:
    a. The determination of the SPI categories in which burnt areas lie for all the year of 2009 and the SPI timescales used in this study.
    b. Based on the result of task 1.a, a detailed analysis of the dry conditions in burnt areas as opposed to the whole study area is done.
2. The comparison of the fire danger levels of EFFIS with the SPI categories to assess the added value of including SPI information in forest fire danger forecasts.

Task 1 is divided in two subtasks. First, the goal is to find the relationship between the location of burnt areas and the water supply conditions in the region at the time of their occurrence. For every month of the year 2009 and for every timescale (1, 3, 6, 9, 12, 24 months), the SPI values are extracted for each burnt area. This provides the frequency of forest fire occurrences per month, timescale and SPI category; thereby permitting the calculation of the total monthly burnt area per SPI timescale and category for the year of 2009. This first part of the analysis results in an overview of the percentage of burnt areas in every SPI category for the analysed timescales.

In the second subtask (task 1.b), the goal is to determine if there is a deterministic process linking the forest fires' occurrences and the SPI values at some specific timescale, or if burnt areas are just randomly located in the study area. This is achieved by comparing the frequency distribution of the SPI values within burnt areas to the distribution of the SPI values in the whole study area. If the SPI values within burnt areas follow the pattern of the correspondent SPI distributions for the whole study area, then there is random process governing their relationship. On the other hand, if the previous condition does not hold, we can assume that there is a deterministic relationship between the burnt areas and SPI categories estimated at some timescale, which is independent of the correspondent SPI distribution in the whole region. To ensure statistical robustness, this analysis is performed for the months during which the frequency of forest fires' is greater than 30 (Murteira et al, 2002; Pestana and Velosa, 2006).

In the analysis related to the second task, we compare the fire danger levels to the SPI categories in which burnt areas occur. The comparison between SPI categories within burnt areas and fire danger categories gives an indication of the months during which long-term drought information is an added value and a complement to the fire danger maps produced by EFFIS.

3. RESULTS

This section summarizes the results of the interplay analysis between drought conditions and the occurrences of forest fires in the Iberian Peninsula in 2009. The results are organized according to the tasks defined in the methodology section.

3.1. Results of Task 1.a – Correspondence between Burnt Areas and SPI on all Timescales

The first result shows the percentage of burnt areas per SPI category for the different SPI timescales, ranging from 1 to 24 months (see Fig. 4). On the one hand, this indicates that nearly 70% of all forest fires took place in areas undergoing extremely dry or severely dry conditions with respect to SPI-24. By including moderately dry category of SPI-24 values, the percentage of burnt areas under dry conditions sums up to almost 90%. On the other hand, the distribution of burnt areas under dry conditions, as measured by the SPI on the timescales between 1 and 9, is always inferior to 40% and merely superior to 50% for SPI-12.

Figure 4 also shows that at most 0.5% of forest fires occurred in areas where the SPI values were indicating wet conditions. This is an important insight, as it suggests that regions under wet SPI categories for all timescales are automatically excluded from potential forest fire danger.

Following from these observations, the results of the first subtask of the study indicate the strongest correspondence between burnt areas and the long-term drought conditions represented by SPI-24 values; with drought conditions referring to the SPI-24 categories of extremely, severely and moderately dry.

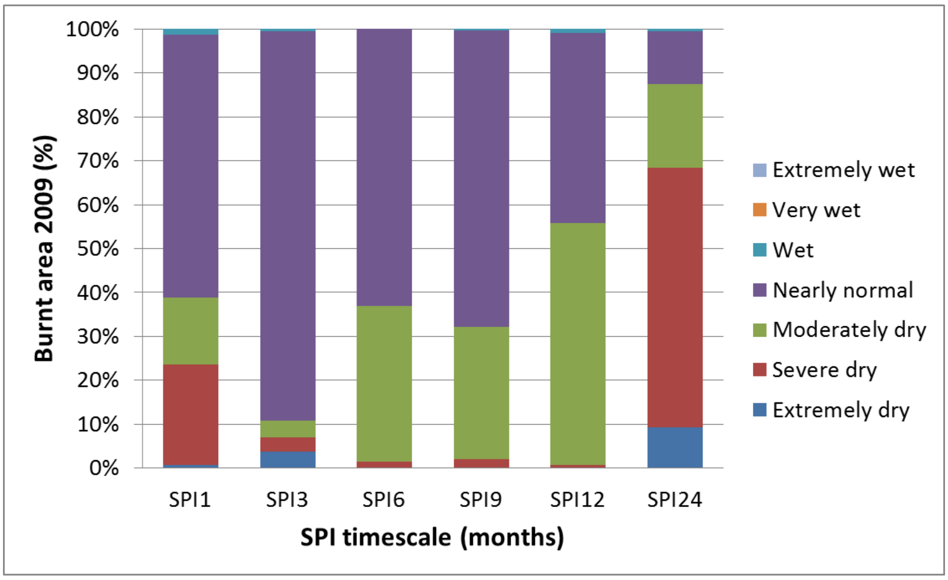
3.2. Results of Task 1.b – Comparison of Dry Conditions in Burnt Areas and Whole Study Area

The focus for the second subtask is set only on the SPI-24, based on the relation found between burnt areas and its values. This task analyses the relationship between the monthly spatial distribution of drought conditions in the whole study area and the drought conditions in burnt areas; as discussed before, this analysis is done for months with more than 30 forest fires: March, July, August, September, October (cf. Fig. 2). The results of this subtask 1.b are summarized in Figure 5.

In the diagram representing March 2009 in Figure 5, we see, for example, that more than 70% of the entire study area undergo nearly normal conditions as indicated by the SPI-24. Regarding the burnt areas, nearly 60% fall into cells that suffer from severely dry conditions and another 40% fall into moderately dry conditions. This pattern is comparable to the other months (August, September, and October); although July is an exception to the case.

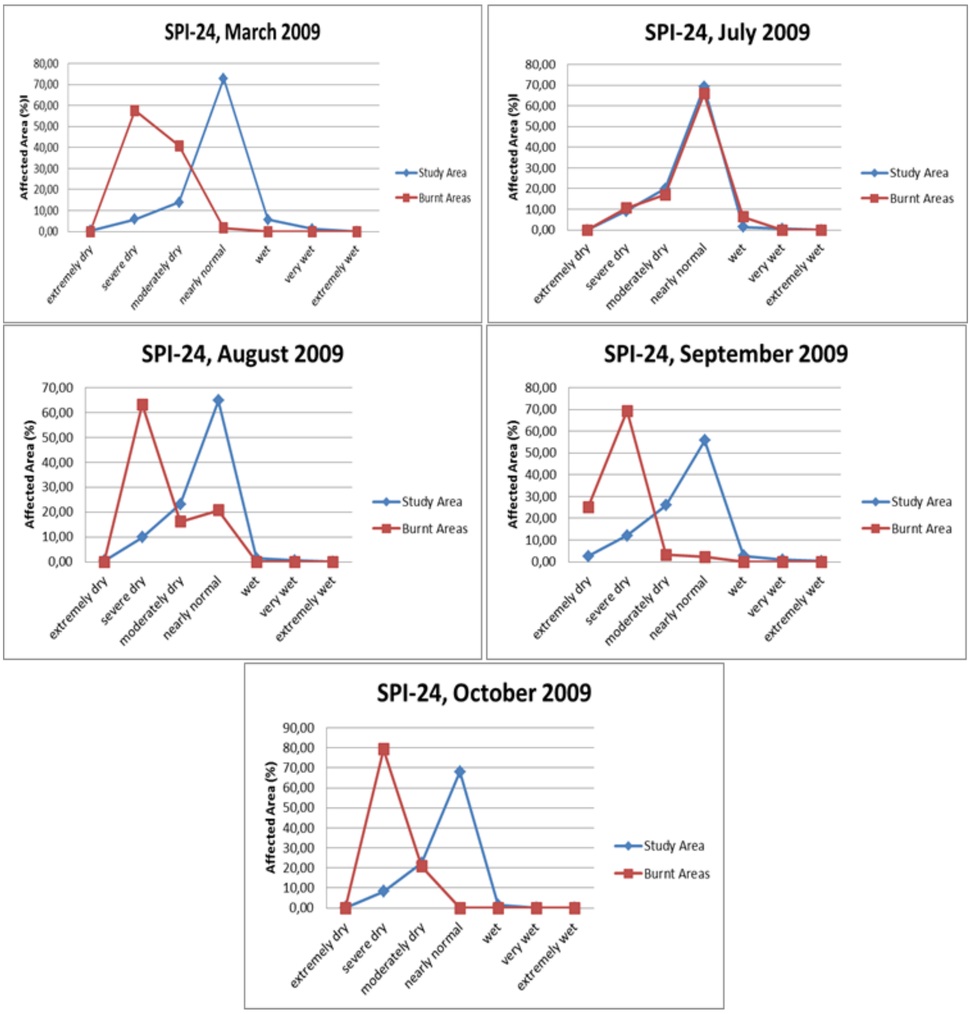
An insight analysis of the situation in the month of July shows, that at the peak of the summer time in the Iberian Peninsula, which is characterized by daily temperatures that can reach 40°C and low relative humidity values, it is normal that all fine fuels that ignite and burn easily (e.g. grass, leaves, bark and twigs) are dry (Carrão et al, 2003). Therefore, independently of drought conditions, there is always a generalized increment of forest flammability that propagates over the entire region.

Figure 4: Overview of Burnt Areas and the Drought Conditions in which They Occurred for the Year 2009



In summary, the results of this subtask show that in four of the five months analysed, the frequencies of SPI-24 categories within the burnt areas do not follow the distribution patterns of the SPI-24 categories for the whole study area (Fig. 5). Furthermore, the SPI-24 values for March, August, September and October, indicate that more than 80% of the burnt areas were always under moderate, severe and extreme drought conditions; although only 30% at maximum of the whole study area showed similar conditions in the same month. Following this association, we suggest that the dry conditions of the SPI-24 do give a deterministic indication of the areas that are more prone to forest fires.

Figure 5: Analysis of the Spatial Distribution of Drought Conditions of Burnt Area Cells in Comparison to the Study Area



3.3. Results of Task 2 – Comparison of Fire Danger Levels and SPI Categories in Burnt Areas

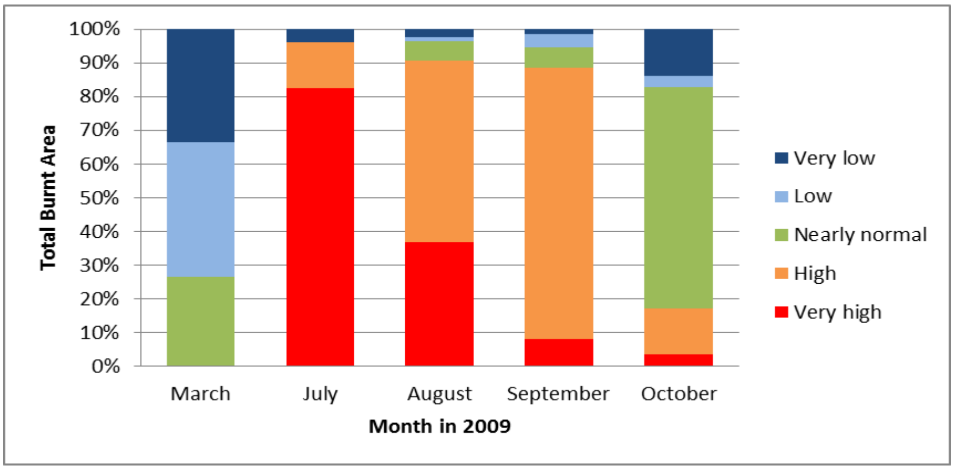
Task 2 of the methodology focuses on the comparison between the fire danger assessment and the drought conditions of SPI-24 for the burnt areas. Again, the focus is only on the SPI-24 as the reported dry conditions for this timescale have the strongest relationship with burnt areas.

For July, August and September, the fire danger in the burnt areas is high and very high (resulting from high temperatures and lack of near-real time precipitation that causes fuel moisture to dry) (Fig. 6). However, it is interesting to note that the fire danger in March and October – months outside the forest fire season – is basically moderate to low in the burnt areas, while the SPI-24 indicates severe dry conditions for burnt areas (Fig.7).

Because the fire danger information derives from data on recent precipitation and daily wetness of vegetation, the increased forest fire danger is certainly correctly reported during the fire season, as nearly no rainfall is expected for the region. However, in March and October – months outside the forest fire season – the fire danger information shows to be moderate to low in the burnt areas. It is interesting to see that as the end of the year approaches and the temperatures get lower and moisture increases, the fire danger categories change immediately their behaviour and this is visible in the assessment for the burnt areas. In contrast, the SPI values in the burnt areas maintain more or less the same pattern along time, which shows severely to moderately dry conditions for almost all burnt areas. This means that if a forest fire occurs outside the forest fire season, it will be most certainly where the vegetation is under long-term dry conditions.

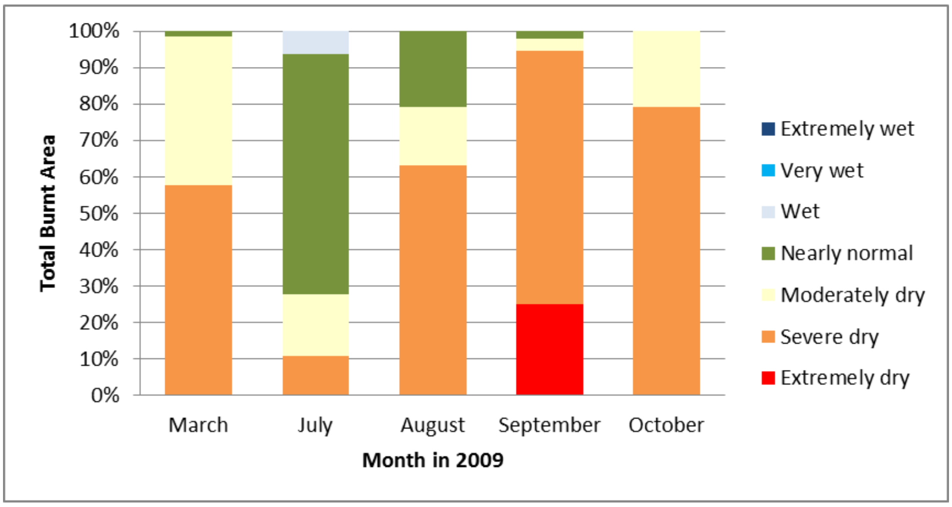
The conclusion derived from this task is that the SPI-24 seems to be useful as a complementary source of information for the assessment of forest fire risk outside the forest fire season.

Figure 6: Percentage of the Burnt Areas per Forest Fire Danger Category for March, July, August, September and October[3]



[3] For 2009 only 5 Forest Fire Danger categories were registered; the category ‚extreme' was added in 2012.

Figure 7: Percentage of the Burnt Areas per SPI-24 Category for March, July, August, September and October



4. DISCUSSION

The main findings of this study are:

- SPI conditions on timescales shorter than 24 months do not appear to be systematically related to the burnt areas. The strongest link between burnt area locations and SPI dry conditions are found for the SPI-24.
- Forest fires do not occur during wet conditions as indicated by the SPI on all timescales (Fig. 4).
- The SPI can serve as an ancillary data source outside the forest fire season.

The objective of this research regarding the evaluation of the added value of information on drought conditions contained in the SPI for the Fire Danger assessment, was met. Based on the results we suggest an inclusion of long-term drought information in the assessment of forest fire danger. This kind of long-term information on precipitation values is currently not included in the EFFIS fire danger assessment. The SPI-24 can complement the forest fire danger assessment mostly outside the forest fire season. The long-term drought index could be used as *a priori* information or as a structural component of EFFIS for increasing the preparedness for forest fires in regions under drought conditions – for the respective months before and after the fire season. The findings of the study are particularly relevant in light of the fact that in March 2009, more than 120 forest fires were larger than 50 ha in size.

A possible explanation for the link between SPI-24 and forest fire locations can be found in reduced groundwater supplies and diminished reservoirs levels. Due to these conditions, the vegetation is unable to extract the expected quantities of water required for normal and thereby dehydrates. When plant cells are deprived of water, they shrink, collapsing in upon themselves and become brittle, thus being more susceptible to forest fire (cf., Reinhard et al, 2005).

The information provided by the SPI is structurally different from the short term precipitation values included in the calculation of the fire weather index. A direct comparison of the drought code of the FWI and SPI, was therefore not considered relevant. To recall, the drought code is based on the precipitation during the preceding 24 hours; the SPI provides an assessment of precipitation values accumulated for at least one month in comparison to long-term mean values of a location. The FWI looks on the ignition risk, and the SPI gives information on the burning risk.

Studies of the correlation between forest fires and drought generally focus more on the use of climatic variables rather than only precipitation: soil moisture, temperature, sunshine, etc. (Billing, 2003; Reinhard, 2005; Xiao and Zhuang, 2007). In the context of developing models for forecasting the influence of drought on a specific fire year, also drivers behind the climatic conditions, such as the El Niño Southern Oscillation, may be considered (Xiao, Zhuang, 2007; Fernandes et al, 2011). In the context of developing models to forecast the influence of drought on a specific fire year, additional drivers behind the climatic conditions, such as the El Niño Southern Oscillation should be considered (Xiao, Zhuang, 2007; Fernandes et al, 2011). In contrast, this study looked at the SPI alone. The SPI may not be sufficient for explaining processes behind the forest fire trends in specific years; the results show, however, that the SPI-24 is a valuable contribution for delimiting areas under risk outside the fire season.

Another study that was using the SPI, did not discuss the different SPI time scales and their interactions with forest fires (Fernandes et al, 2011). They used only the SPI-3 and focused on the burnt areas occurring only during the forest fire season of their study area, which was the Amazon rainforest. In our study we did not find a strong correspondence between burnt areas and dry conditions shown by the SPI-3. In fact, because the absence of rainfall is a normal situation during the summer period in the Iberian Peninsula, the short-term SPIs do not detect a divergence from average precipitation values and communicates mostly near normal conditions for the whole region. Thus, we conclude that the climatic characteristics of the study areas do obviously have an influence on the choice of the SPI and the period for which conclusions can be derived.

As mentioned in Xiao and Zhuang (2007), climatological studies often make use of the Palmer Drought Severity Index (PDSI) for assessing susceptibility to forest fires. However, the PDSI is more complex in its calculation than the SPI and has a fixed accumulation period of 12 months that relates only to SPI-9 and SPI-12 (Lloyed-Hughes and Saunders, 2002). Since dry conditions shown by the SPI-24 had the highest correlation with burnt areas – a timescale not covered by the PDSI – we argue that the focus on the SPI is valuable.

Our study showed that the water supply conditions in the whole study area and for all five months resemble normal distributions. Theoretically, since the SPI is a relative measure, which is based on comparing current accumulated precipitation values to long-term average precipitation time-series, it is expected that only a small part of the whole study area each month (according to Table 1) is under dry conditions. This is verified within the results and adds to the reliability of SPI for monitoring drought intensities, as previously shown by Mckee et al (1993).

The study was performed for one year (2009) and one study area (Iberian Peninsula) only. We also did not consider the causes of forest fires, which are not only natural, but also human-induced. The results are, nevertheless, indicative and we propose the establishment of a repeated collaboration and the setting-up of an infrastructure to facilitate the exchange of data between the disciplines (see section 5). The operational usage of the SPI-24 as complementary information may add a real-world verification of the study results.

5. DATA EXCHANGE BETWEEN THE FORESTRY AND DROUGHT INFRASTRUCTURES

Both EFFIS and EDO are Web-based systems that are underpinned by Web standards defined by the Open Geospatial Consortium (OGC). These systems connect to thematically related resources following interoperability arrangements and provide an infrastructure consisting of map viewers, metadata catalogues, and Web processing services (Fig.8). They are integrated in the spatial data infrastructure (SDI) established in the course of the EuroGEOSS project by the EuroGEOSS Discovery Broker.

This section outlines how the required data can be exchanged between EDO and EFFIS for putting our findings into practice. Two solutions for the transfer of SPI-24 data to EFFIS are possible. The short to medium term solution is to extend the Web Map Service (WMS) provided by EDO with the SPI-24 layer and include the layer within the EFFIS Current Situation[4]. This would give an additional layer to help with the monitoring of forest fires and better assist fire experts and decision makers to identify areas that are more susceptible due to prolonged water stress.

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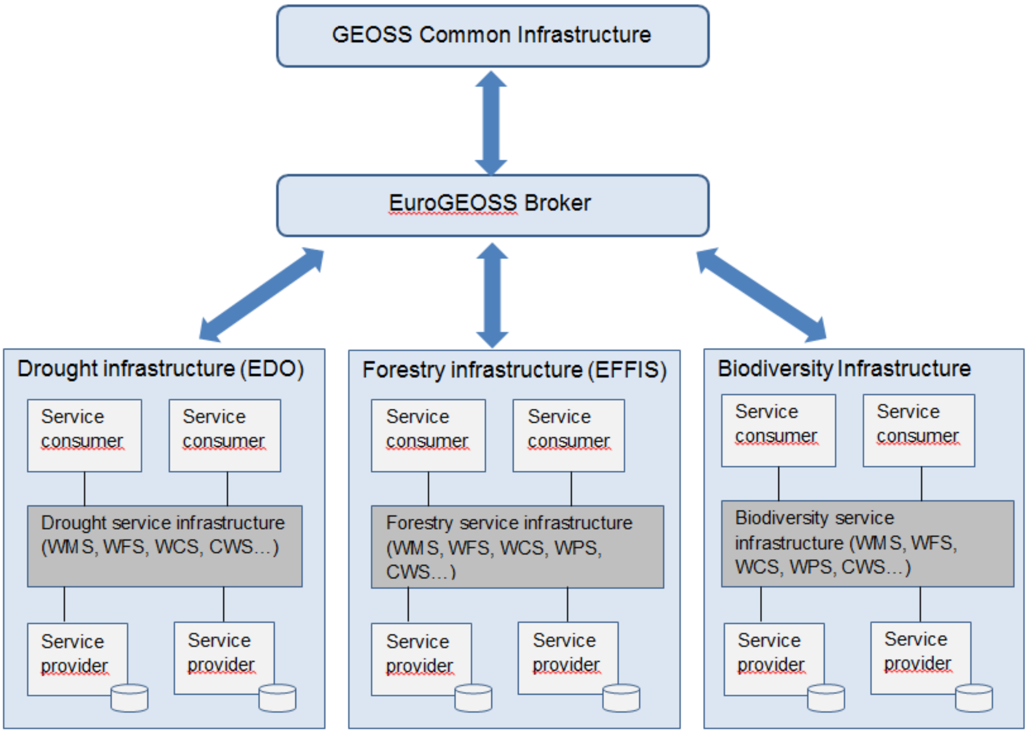
[4] http://effis.jrc.ec.europa.eu/current-situation

Figure 8: Interlinkage of Thematic Infrastructures in the EuroGEOSS Project (after EuroGEOSS 2012)



A longer term solution would be an integration of the SPI-24 into the EFFIS Fire Danger model. For this solution, the SPI-24 has to be provided as a Web Coverage Service (WCS) that would be downloaded by EFFIS at regular intervals either directly from EDO or accessed through the EuroGEOSS Discovery Broker. In this manner, the SPI-24 could be used as additional explanatory variable within the forest fire danger assessment of EFFIS. Further research would have to support the identification of a correct weighting scheme for SPI-24, since standard daily meteo data (temperature, humidity, accumulated rainfall, etc.) are still going to be more important for the calculation of the FWI than SPI-24, but as demonstrated, the integration of the latter will improve the model.

Such an integration of EDO data into EFFIS, would provide more contextual and ancillary information to the existing EFFIS user base, which includes civil protection authorities and forest services in countries of the European Union as well as the European Commission and Parliament.

There are two aspects that require further investigation before the implementation of a spatial data service within an operational context: these are the difference in temporal availability and spatial resolution between FWI and SPI-24 data. The FWI is calculated daily, whereas the SPI is a monthly index that is available at the end of each month. It has to be evaluated if the SPI-24 of the previous month provides sufficiently correct information on current dry conditions. We expect that the long-term information given by the SPI-24 supports the finding of susceptible areas, even if this assessment does not happen in real time.

Regarding the spatial resolution, the SPI-24 for Europe coming from EDO has a rather coarse resolution (25 x 25km), which restricts the level of detail on which the drought-related information can be used. The information does only provide an overview of the drought situation in a certain area as shown in Ceglar et al (2012). Improving the meteorological data is possible with the inclusion of data at the national scale, which is worked on in the context of EDO. A discussion with the future users of the system could show whether the spatial resolution of the drought information is detailed enough or not.

6. CONCLUSIONS AND FUTURE WORK

One challenge addressed in the context of the SDI developed during the EuroGEOSS project is to use available data services across disciplines for generating added value. Based on the observation of a difference in temporal scale of drought information used in the Forest Fire Danger assessment of EFFIS and drought information provided by the drought thematic area, we addressed this challenge in this study. The purpose of this analysis was to evaluate the potential of using long-term drought information for complementing the Fire Danger assessment done in EFFIS. The results provide first scientific evidence that the SPI-24 drought index can be used as added piece of information outside the forest fire season.

The added value of this research is to propose not a definition of another fire danger index for near-real time monitoring, but to propose a long-term stratification of the risk that can serve as *a priori* information for forest fire danger forecasting. Further work is required for confirming the results in a larger study looking at the relation between drought conditions and forest fire locations over several years.

Based on the results we suggest that the regular exchange of data on long-term drought conditions between EDO and EFFIS constitutes an added value to the Forest Fire Danger forecast. It is evident that the implementation of this data exchange between the thematic areas of forestry and drought is facilitated by the EuroGEOSS framework that builds upon INSPIRE specifications, OGC web services and the EuroGEOSS Discovery Broker. After solving issues regarding the frequency of the provision of drought-related data and limitations due to their spatial resolution, the contribution of the data exchange can be practically tested and possibly extended to all Mediterranean regions of Europe and beyond.

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REFERENCES

Agnew, C.T. (2000). Using the SPI to Identify Drought. *Drought Network News*, 12(1): 6-12.

Billing, P. (2003). “Impact of the Drought on Forest Fires”, *DroughtCom Workshop: Improving the Communication of Climate Information*, *July 22-23 2003, Melbourne, Australia,* pp. 1-6, at http://www.bom.gov.au/climate/droughtcom/droughtcom_abstracts.pdf [accessed 6 August 2012]

Caetano, M., Freire, S. and H. Carrão (2004). “Fire risk mapping by integration of dynamic and structural variables”, in Goossens, R. (Ed.) *Remote Sensing in Transition*. Rotterdam: Millpress, pp. 319-326.

Camia, A., Barbosa, P., Amatulli, G. and J. San-Miguel Ayanz (2006) “Fire danger rating in the European Forest Fire Information System (EFFIS): current developments”, *Proceedings of 5th International Conference on Forest Fire Research, November 27-30 2006, Coimbra, Portugal*.

Carrão, H., Freire, S. and M. R. Caetano (2003). “Fire risk mapping using satellite imagery and ancillary data: Towards operationality”, in Owe, M., d'Urso, G. and L. Toulios (Eds.) *Remote Sensing for Agriculture, Ecosystems and Hydrology IV, Proceedings of SPIE*, pp. 154-165.

Ceglar, A., Vicente-Serrano, S., Medved-Cvikl, B., Morán-Tejeda, E., López-Moreno, J. I., González-Hidalgo, J. C., Camarero, J.J., Pasho, E. and L. Kajfež-Bogotaj (2012) “Assessment of multi-scale drought datasets for multidisciplinary applications”, *EuroGEOSS Conference 2012, January 24-27 2012*, *Madrid, Spain,* at http://www.eurogeoss.eu/conferences/2012/pdfs/22.pdf [accessed 3 August 2012].

Craglia, M., Goodchild, M. F., Annoni, A., Camara, G., Gould, M., Kuhn, W., Mark, D., Masser, I., Maguire, D., Liang, S. and E. Parsons (2008). Next-Generation Digital Earth: A position paper from the Vespucci Initiative for the Advancement of Geographic Information Science, *International Journal of Spatial Data Infrastructures Research*, 3: 146-167.

Craglia, M., Nativi, S., Diaz, L. and L. Vaccari (2012). “Towards Multi-Disciplinary Interoperability: the EuroGEOSS contribution”, *EuroGEOSS Conference, January 24-27 2012 Madrid, Spain,* at http://www.eurogeoss.eu/conferences/2012/pdfs/31.pdf [accessed 3 August 2012].

EuroGEOSS (2012). EuroGEOSS Final Report, at http://www.eurogeoss.eu/Documents/EuroGEOSS_final_public_report.pdf [accessed 14 September 2012]

Fernandes, K., Baethgen, W., Bernardes, S., DeFries, R., DeWitt, D. G., Goddard, L., Lavado, W., Lee, D. E., Padoch, C, Pinedo-Vasquez, M., and M. Uriarte (2011). North Tropical Atlantic influence on western Amazon fire season variability, *Geophysical Research Letters,* 38 (L12701), pp. 5.

GEO (2011). GEO 2012-2015 Work Plan, at http://www.earthobservations.org/documents/work%20plan/GEO%202012-2015%20Work%20Plan_Rev1.pdf [accessed 8 February 2012].

Gore, A. (1998). The Digital Earth: Understanding our planet in the 21st century. Given at the California Science Center, Los Angeles, California, on January 31, 1998.

Gouveia, C., Trigo, R.M., and C.C. DaCamara (2009). Drought and vegetation stress monitoring in Portugal using satellite data, *Natural Hazards and Earth Sciences,* 9: 185-195.

Hayes, M., Svoboda, M.D., Wilhite, D.A. and O. V. Vanyarkho (1999). Monitoring the 1996 drought using the Standardized Precipitation Index, *Bulletin of the American Meteorological Society*, 80(3): 429-438.

Haylock, M.R., Hofstra, N., Klein Tank, A.M.G., Klok, E.J., Jones, P.D. and M. New (2008). A European daily high-resolution gridded dataset of surface temperature and precipitation for 1950–2006, *Journal of Geophysics Research,* 113(D20119), pp. 12.

Hosking, J. M. (1990). L-moments: Analysis and Estimation of Distributions using Linear Combinations of Order Statistics, *Journal of Royal Statistical Society*, 52(1): 105-124.

INSPIRE (2011). Infrastructure for Spatial Information in the European Community, at http://inspire.jrc.ec.europa.eu/ [accessed 6 August 2012].

Lloyed-Hughes, B. and M.A. Saunders (2002). A Drought Climatology for Europe, *International Journal of Climatology*, 22: 1571-1592.

McArthur, A.G. (1966). *Weather and grassland fire behaviour*, Leaflet No. 100, Canberra: Australian Forestry and Timber Bureau.

McInerney, D., Bastin, L., Diaz, L., Figueiredo, C., Barredo, J.I. and J. San-Miguel Ayanz (2012). Developing a Forest Data Portal to Support Multi-Scale Decision Making, *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, accepted for publication, pp. 8.

McKee, T., Doesken, N. and J. Kleist (1993). “The relationship of drought frequency and duration to time scales”, *Proceedings 8th Conference on Applied Climatology, January 17-22 1993, Anaheim, California,* pp.179-184. Boston, Massachusetts: American Meteorological Society.

Merino-de-Miguel, S., González-Alonso F., García-Gigorro S., Roldán-Zamarrón A. and J.M. Cuevas (2005). “Is it possible to timely and accurately estimate wildfire burnt areas using remote sensing techniques?”, in Oluić, M. (Ed.) *New Strategies for European Remote Sensing – Proceedings of the 24th Symposium of the European Association of Remote Sensing Laboratories, May 25-27 2004, Dubrovnik, Croatia*. Rotterdam: Millpress, pp. 81-87.

MINADERP, Ministério da Agricultura, do Desenvolvimento Rural e das Pescas (2011). Portaria n.º 165/2011, Diário da República, 1ª série - N.º 77 - 19 de Abril de 2011.

Murteira, B., Ribeiro, C. S., Silva, J. A. and C. Pimenta (2002). *Introdução à Estatística*, Lisbon: McGraw-Hill.

Pestana, D. D. and S. F. Velosa (2006). *Introdução à Probabilidade e à Estatística, 2nd Ed.,* Lisbon: Fundação Calouste Gulbenkian.

Reinhard, M., Rebetez, M. and R. Schlaepfer (2005). Recent climate change: Rethinking drought in the context of Forest Fire Research in Ticino, South of Switzerland, *Theoretical and Applied Climatology*, 82(1-2): 17-25.

Schmuck, G., San-Miguel-Ayanz, J., Camia, A., Durrant, T., Santos de Oliviera, S., Boca, R., Whitmore, C., Giovando, C., Libertá, G., and E. Schulte (2010). *Forest Fires in Europe 2009,* JRC Scientific and Technical Reports, Luxembourg: Publications Office of the European Union.

Swetnam, T. (2001). “Spatial and temporal coherence of forest fire and drought patterns in the western Unites States”, *Fourth Symposium on Fire and Forest Meteorology, November 12-15 2001, Reno, Nevada.* Boston, Massachusetts: American Meteorological Society.

Vicente-Serrano, S.M., González-Hidalgo, J.C., de Luis, M. and J. Raventós (2004). Drought patterns in the Mediterranean area: the Valencia region (eastern Spain), *Climate Research*, 26: 5-15.

Vogt, J., Barbosa Ferreira, P., Hofer, B. and A. Singleton (2011). Developing a European Drought Observatory for monitoring, assessing and forecasting droughts across the European Continent, *Geophysical Research Abstracts Volume 13*. Copernicus Publications.

WMO, World Meteorological Organization (2011). *Guide to Climatological Practices WMO-No. 100,* Geneva: World Meteorological Organization.

Xiao, J. and Q. Zuang (2007). Drought effects on large fire activity in Canadian and Alaskan forests, *Environmental Research Letters*, 2, pp. 6.

Van Wagner, C.E. (1987). *Development and Structure of the Canadian Forest Fire Weather Index System,* Forestry Technical Report 35, Ottawa: Canadian Forestry Service, Headquarters.