ERA4CS SERV_FORFIRE

Integrated services and approaches for Assessing effects of climate change and extreme events for fire and post fire risk prevention

Mid-term Report:

M.3 Modelling concluded. Start of the case study applications

WP3: Seasonal fire risk occurrence: model development and setup at multiple temporal and spatial scales

WP leader: Finnish Meteorological Institute

http://www.jpi-climate.eu/nl/25223459-SERV_FORFIRE.html

Date: January 2019

WP number		3
WP name		Seasonal fire risk occurrence: model development and setup at multiple temporal and spatial scales
WP leader	**Organisation**	Finnish Meteorological Institute
	Representative	Andrea Vajda

Authors:

Andrea Vajda, Cecilia Karlsson, Otto Hyvärinen, Mikhail Sofiev, Tero Partanen – Finnish Meteorological Institute (FMI)

Rosa Lasaponara, Monica Proto - Consiglio Nazionale delle Ricerche, Istituto di Metodologie per l'Analisi Ambientale (CNR–IMAA)

Massimiliano Pasqui, Elena Rapisardi, Ramona Magno, Edmondo Di Giuseppe, Leandro Rocchi, Tiziana De Filippis - Consiglio Nazionale delle Ricerche, Istituto di Biometeorologia (CNR-IBIMET)

Vassiliki Varela, Diamando Vlachogiannis - National Center for Scientific Research "Demokritos" (NCSRD)

Mirek Trnka – CzechGlobe, Global Change Research Institute of the Czech Academy of Sciences (GCRI)

Peter Van Velthoven, Folmer Krikken, Geert Jan van Oldenborgh - The Royal Netherlands Meteorological Institute (KNMI)

Contents

1 Executive Summary

This report provides an overview of the models and statistical methods and procedures developed and implemented for monitoring and estimating and forecasting drought, fire danger, fire occurrence and emission on various time scales on local and European level, summarizing the results of the work done in the first phase of Work Package 3. Applying the models and approaches developed serve the implementation of pre-operational and operational services that facilitate the preparedness and efficiency of fire and risk management, decision-making and planning authorities, improves the preparedness and safety level of our societies and reduces the economic costs of the impact of climate variability on fire activity.

The input data used in models and statistical analyses implied meteorological data from various sources, such as in-situ data, satellite data, re-analysis data, prediction model output at various time scale and also climate projection data by extending the models to future trends simulations, satellite data and vegetation related data from various sources. Various widely used fire indices and their components have been used, such as the Canadian Fire Weather Index (FWI) system, the Finnish forest fire Index (FFI) and the Forest Fire Danger Index (FFDI) used in Australia. The methodologies applied varies among the models and approaches implemented. The time scale covered in the statistical analysis and modelling work covers daily, sub-seasonal, seasonal and climate scenarios.

The models and forecast systems designed and developed, and the statistical analysis applied during the first phase of the Work Package, and described in this report are:

- fire risk mapping model developed and applied for Basilicata region (Italy)
- fire site simulator applied for Basilicata region (Italy)
- satellite based fire bunt area and burn severity mapping model applied for Potenza (Italy)
- drought climate service and seasonal forecasting for Tuscany (Italy)
- weather-based forecasting global model of wildfire emission
- forest fire danger forecasting model at seasonal and sub-seasonal scale for boreal forest conditions (Finland)
- fire danger forecasting model at seasonal scale for Mediterranean conditions (Greece)
- seasonal statistical empirical forecasting system of the monthly drought code
- analyses of various fire danger monitoring methods at high (500 m) resolution over Czech Republic
- analysis of climate attribution to extreme forest fire events

The implemented statistical approaches and methods will be further applied within the framework of SERV_FORFIRE joint activities in the pilot area selected by the partners: the Basilicata region in Italy, Tuscany region in Italy and Eastern Attika in Greece. The forest fire danger forecasting model developed for boreal conditions will be produced for the whole Finland and tested by FMI together with the stakeholders. The approaches laboured for the analysis of various fire danger monitoring methods and estimation of trend for the future fire danger will be applied for Czech Republic. In addition estimation of trend for the future fire risk will be provided for Greece.

2 Introduction

Recognizing the scale and complexity of wild fires and the anticipated intensification in the fire regimes the SERV_FORFIRE project will provide comprehensive investigations devised for the different phases of fire management (pre and post fire) and for the different ecosystems and geographic areas ranging from Southern to Northern Europe. One of the main objectives of the project is to set up pre-operational and operational services for drought and fire monitoring and mitigation facilitating the preparedness and efficiency of decision-making and planning authorities.

In the Work Package 3 of the project, Seasonal fire occurrence – Model development and setup at multiple temporal and spatial scales, the main objective is to design and implement pre-operational and operational services for drought, fire risk and fire occurrence monitoring and forecasting for sub-seasonal and seasonal scale and information on long-term trends in drought and fire risk using climate scenarios in order to provide useful information for users and decision makers. For this purpose a set of models and statistical methods and procedure were developed exploiting as much as possible all the information available from European level down to local scale using as reference cases the test areas selected in diverse geographical areas. The developed approaches provide estimation of fire risk and occurrence, fire burnt area, fire expansion, fire emission, drought and fire risk forecasting at for estimating drought and fire danger at diverse temporal and spatial scale. The time frame covered ranges from daily to sub-seasonal, seasonal and climate projection scale. The outputs of the modelling activities, including the models developed and the statistical approaches applied so far for fire risk and occurrence estimation are presented in this report. The developed models and forecasting systems will be applied on the test areas selected and described in the project.

The following drought and fire regime related models has been developed and statistical methods applied within the work package by the partners according to their field of expertise:

- Fire risk mapping model, fire site simulator and satellite based fire bunt area and burn severity mapping was performed by CNR IMAA
- Drought climate service and seasonal forecasting for Tuscany implemented by CNR IBIMET
- Weather-based global forecasting model of wildfire emission was developed by FMI
- Forest fire danger forecasting model at seasonal and sub-seasonal scale for boreal forest conditions (Finland) was developed by FMI
- Fire danger forecasting model at seasonal scale for Greece developed by NCSRD
- Analyses of various fire danger monitoring methods at high (500 m) resolution over the whole Czech Republic (and Slovakia) performed by GCRI
- Climate attribution studies to extreme forest fire events performed by KNMI

- Seasonal statistical empirical forecasting system of the monthly drought code developed by KNMI.

The models and statistical analyses implied meteorological data from various sources, such as in-situ data, satellite data, re-analysis data, prediction model output at various time scale and also climate projection data by extending the models to future trends simulations, satellite data and vegetation related data from various sources. The implemented models and prediction systems will be applied and/or tested together with the users in the pilot areas selected by the project partners covering various areas from Europe.

3 Statistical analysis and modelling of present and future trends in fire risk, fire occurrence and fire emission

3.1 Fire risk mapping model for Italy (CNR IMAA)

The Fire risk assessment (developed for the Basilicata Region and operationally applied therein since 2008 up to now) takes into account the most relevant components associated to fire occurrence (Fig. 3.1).

To estimate when and where the fire will produce undesired effects, we modelled both (a) fire ignition and propagation potential and (b) fire vulnerability. Following this approach, a comprehensive fire risk assessment system was devised and optimized over the years.

The fire risk estimation is based on a weighted additive model in which the procedure used is similar to the typical multi-criteria analysis. The objective is achieved by combining the factors used by assigning a weight to each of them. Therefore, each parameter is processed as an information layer in which the factor is classified based on the degree of danger that it poses. The result is a dynamic final map of danger, according to the criteria and the coefficients established by the model.

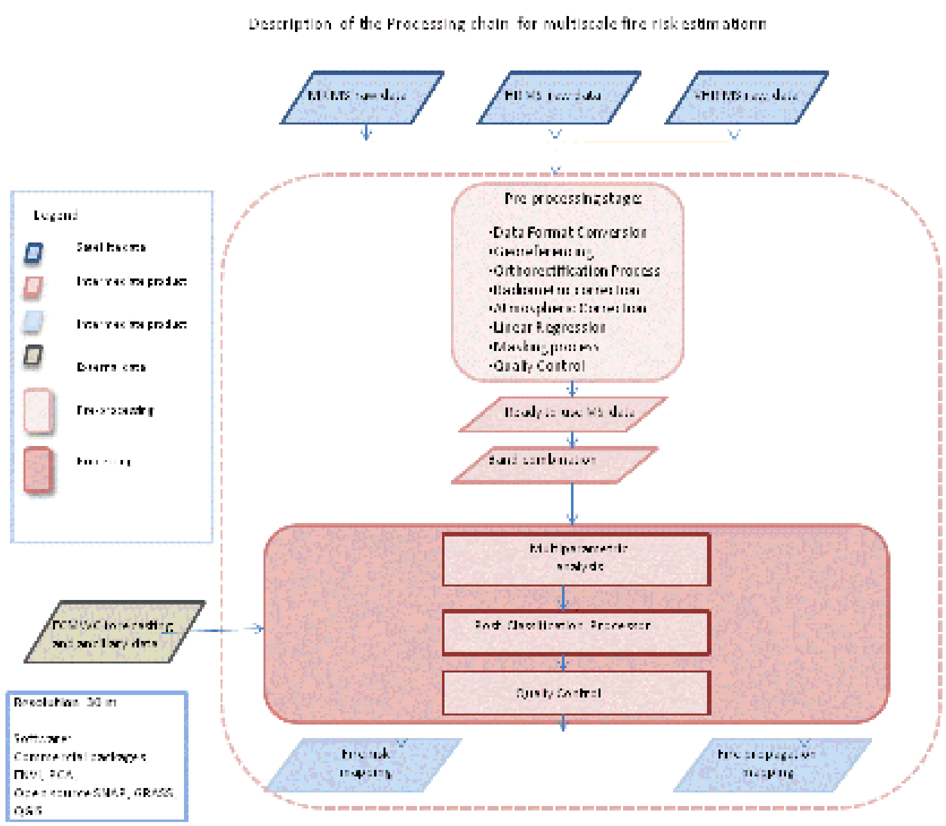

Fig. 3.1 Fire risk mapping model.

From the operational point of view, for the region Basilicata during the period of maximum danger for fires (usually from July to September), fire danger maps are systematically processed daily, whereas in other periods the fire danger maps are provided on a weekly or decadal basis (depending on cloud cover). The maps were drawn at the highest MODIS resolution (250 meters).

During summer 2018 a comparison between EFFIS maps and Firesat maps have been carried out (Fig. 3.2).

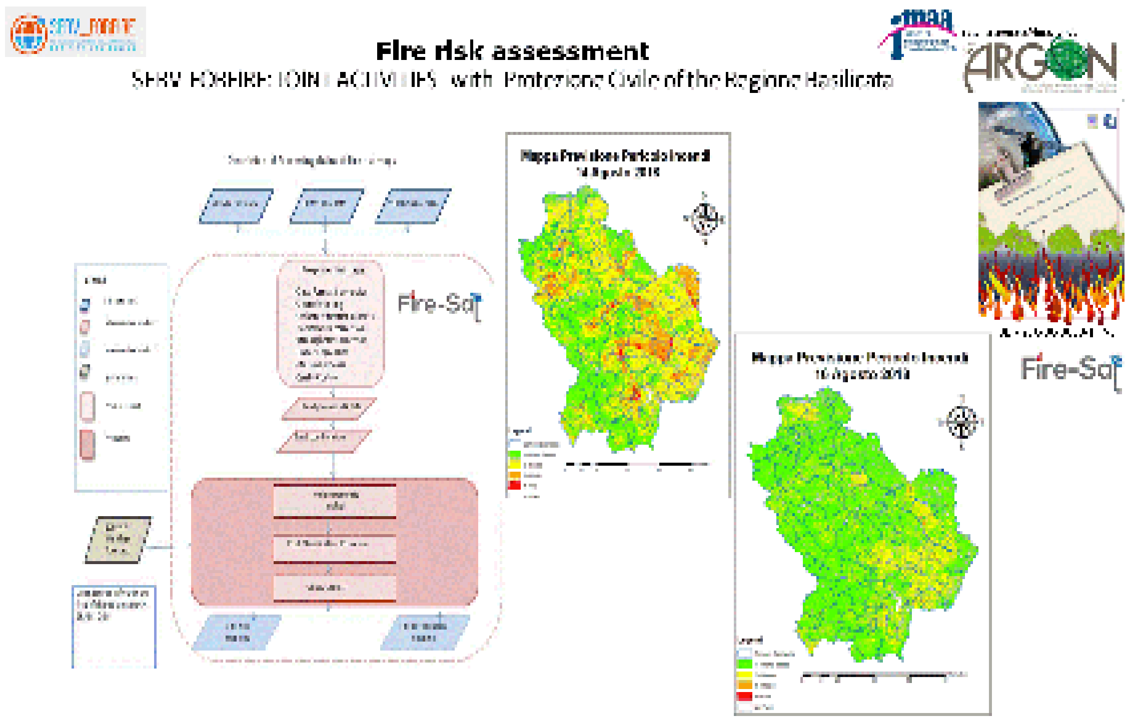

Fig. 3.2 Fire risk maps obtained for the Basilicata region.

3.2 Fire site simulator (CNR-IMAA)

The simulation of fire expansion is made using a computer simulation model FIRESITE (https://www.firelab.org/project/farsite) that is an open software developed by the USA forestry service for fire growth simulation modeling FARSITE, includes existing fire behavior models for surface, crown, spotting, point-source fire acceleration, and fuel moisture. The model's components and assumptions are documented. Simulations were run for simple conditions that illustrate the effect of individual fire behavior models on two-dimensional fire growth.

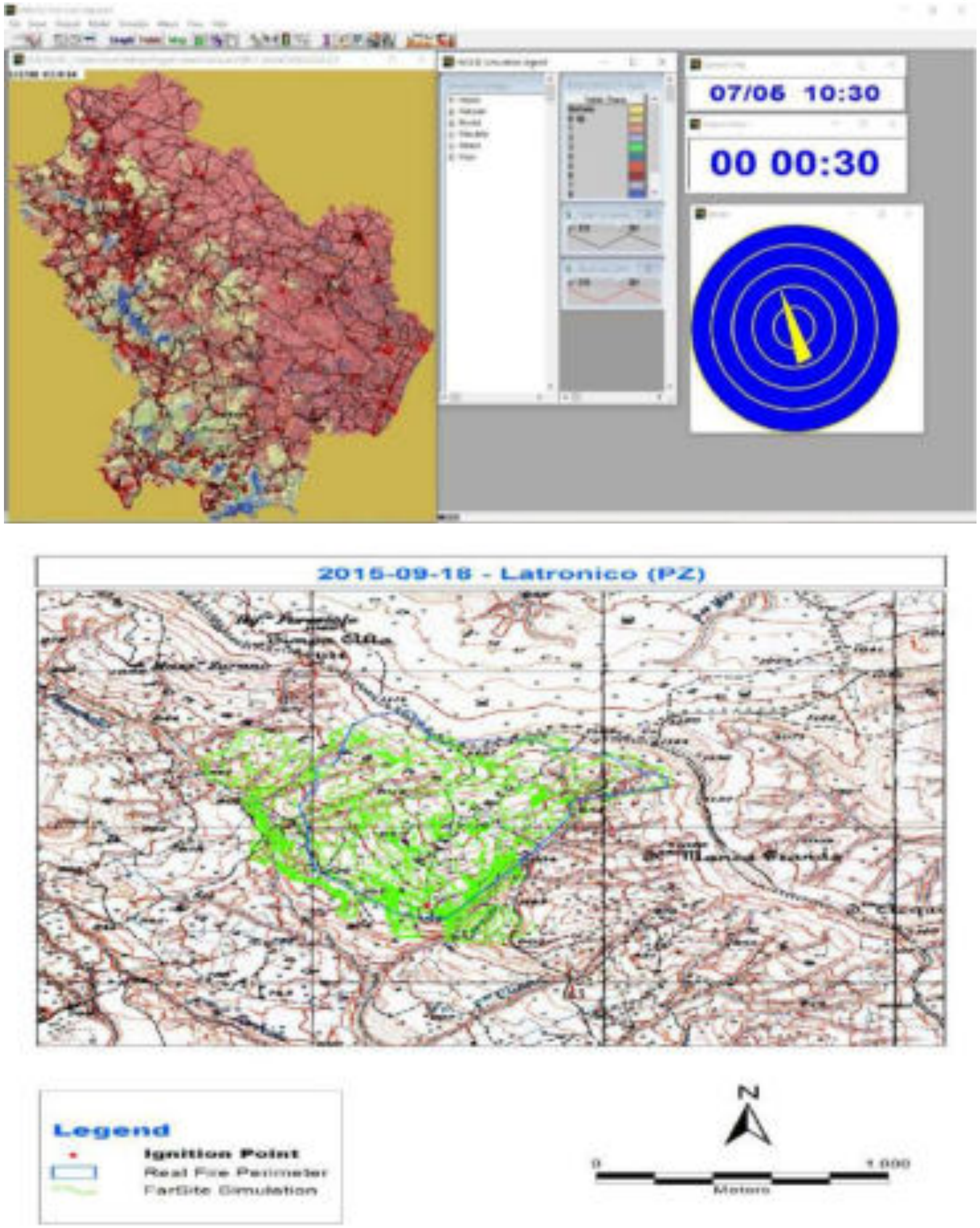

Fig.3.3 The FARSITE Simulator (top) and the map of fire expansion (bottom) as obtained for the Latronico fire occurred in Basilicata region on 18 September 2015.

As an example, Figure 3.3 shows the fire site simulator and the map of fire expansion as obtained for the Latronico fire occurred on 18 September 2015 in Basilicata region. The blue line shows the real expansion of fire and the green area the expansion as simulated by FARSITE (https://www.firelab.org/project/farsite) an open software developed by the USA forestry service for fire growth simulation modeling.

Fig.3.4 Fire site simulation for Maratea fire and mapping of burnt areas and fire severity using sentinel 2 data.

3.3 Satellite based fire bunt area and burn severity mapping

The model developed for the identification and mapping of burnt areas and fire severity (Fig 3.5) is based on the joint use of satellite Sentinel 1 and or Sentinel 2 data, statistical analysis and unsupervised classification to automatically map areas affected by fire, estimate burn severity, and capture post fire feature patterns.

Investigations into a fire burnt area were conducted in the south of Italy from a fire that occurred on 10 August 2017, affecting both the protected natural site of Pignola (Potenza, South of Italy) and agricultural lands located in southern part of Italy (Fig. 3.6).

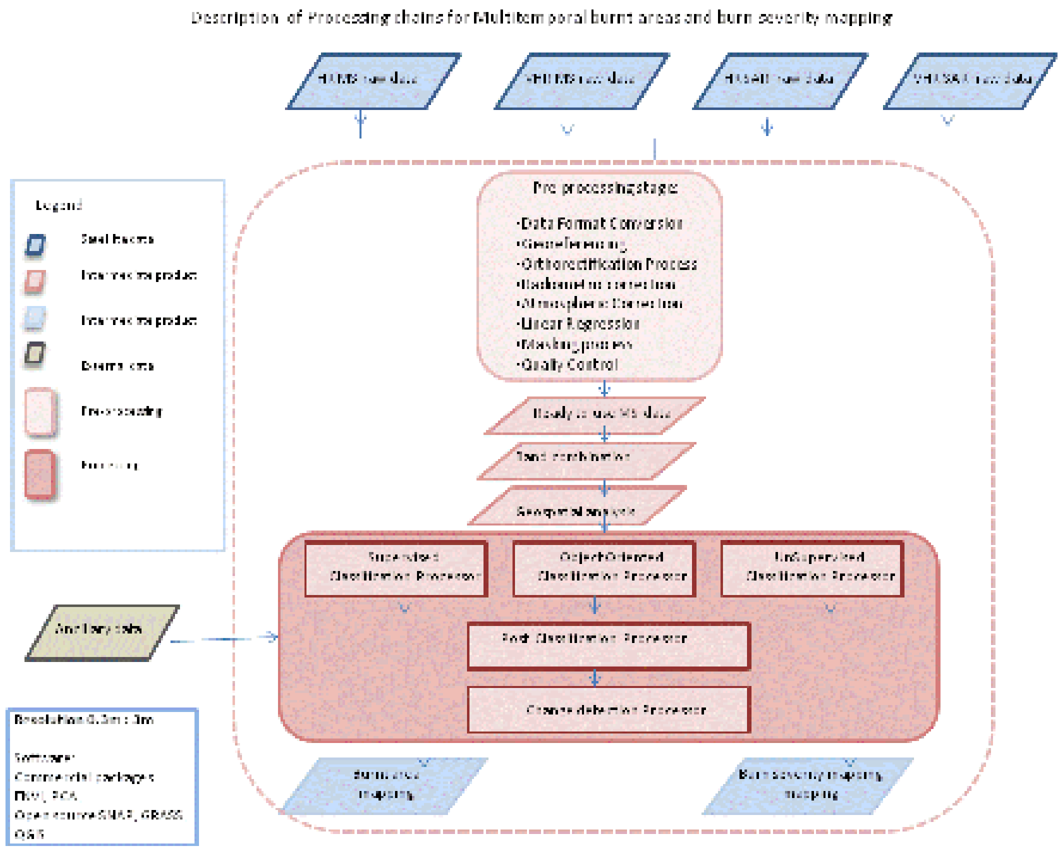

Fig. 3.5 Flow chart of methodology for the identification and mapping of burnt areas and burn severity.

Sentinel 2 data were processed to identify and map different burnt areas and burn severity levels. Local Index for Statistical Analyses LISA were used to overcome the limits of fixed threshold values and to devise an automatic approach that is easier to re-apply to diverse ecosystems and geographic regions. The validation was assessed using 15 random plots selected from in situ analyses performed extensively in the investigated burnt area. The field survey shows a success rate of around 95%, whereas the commission and omission errors were around 3% of and 2%, respectively. Overall, our findings indicate that the use of Sentinel 2 data allows the development of standardized burn severity maps to evaluate fire effects and address post-fire management activities that support planning, decision-making, and mitigation strategies.

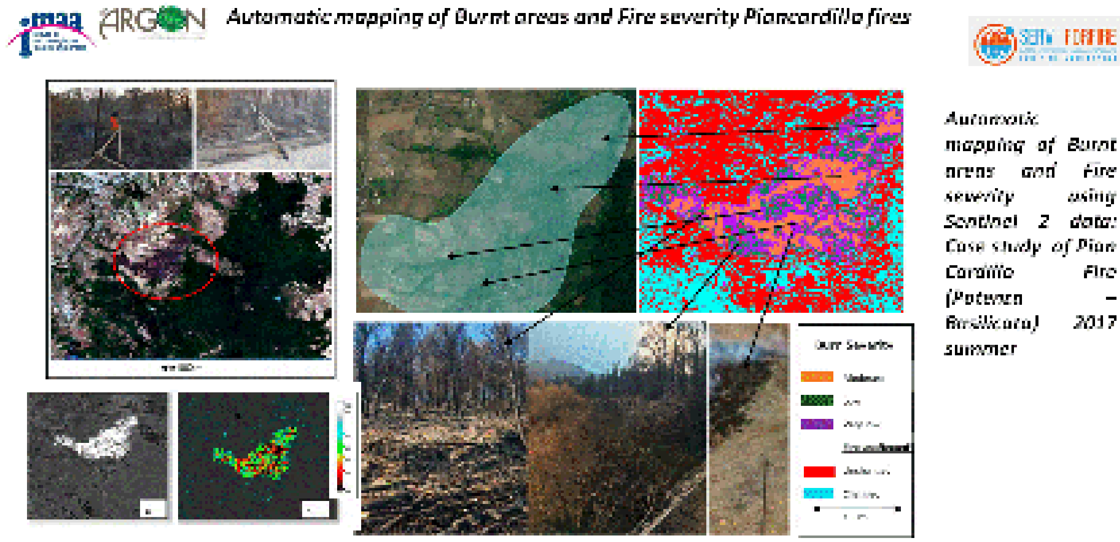

Fig. 3.6 Investigations were carried out using Sentinel 2 data into a fire occurred on 10 August 2017 in Basilicata. The fire affected both the protected natural site of Pignola (Potenza, South of Italy) and agricultural lands (extracted by Lasaponara et al., 2018).

Fig. 3.7 Study area related to the test of Sentinel 1 for mapping burnt areas and burn severity. Ciano dots indicate the areas of the field survey

Over the years, the majority of space based studies on fire and fire impact on vegetation have been mainly based on optical data, whereas a few analyses used satellite Synthetic Aperture Radar (SAR). In the framework of SERV_FORFIRE investigations have been also performed on SAR Sentinel-1 sensors for mapping burnt area and characterize fire severity. To this aim, we focused on a fire occurred on 13th July 2017 in Metaponto (South of Italy); Figure 3.7 shows the field where survey was conducted for the validation purposes. The study area is characterized by uniform topography and vegetation cover (Pinus Alepensis). This homogeneity, coupled with the total absence of precipitation for the whole investigated period, makes Metaponto an excellent case study for investigating and modelling burnt scars and fire severity using Sentinel-1. Both VH and VV polarizations were considered. Radar Burn Difference (RBD) and Radar Burn Ratio (RBR) were computed between Sentinel-1 data acquired before and after the fire using both single and time averaged scenes (to reduce speckle noise effects). The most marked differences between burnt and un-burnt areas were observed in the VH polarization of both RBD and RBR. To identify different levels of fire severity without using fixed thresholds, burnt areas were enhanced using Getis-Ord statistics and categorized using ISODATA unsupervised classification. The pioneering approach herein proposed pointed out that the time averaged ratio of VH polarization of Sentinel-1 well performs in mapping burnt area and severity categorization.

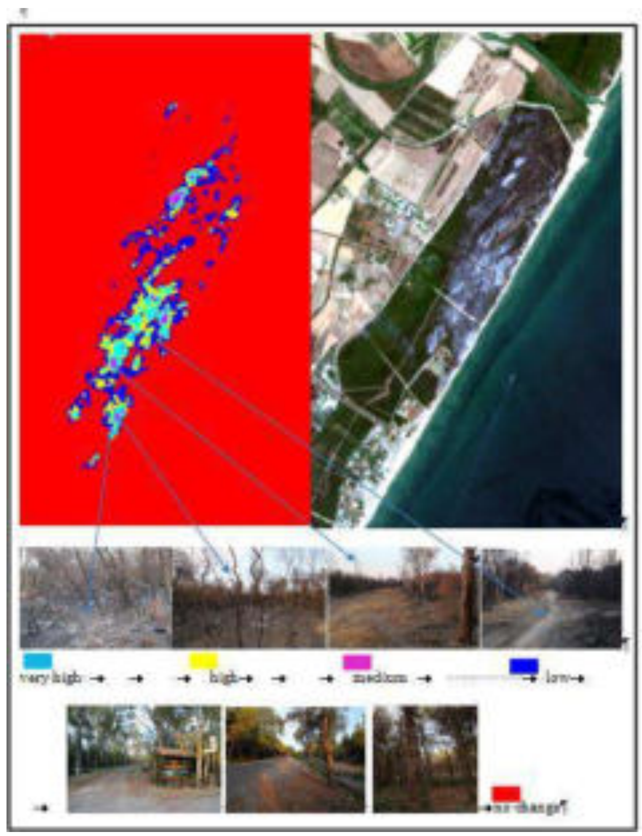

Fig. 3.8 Categorized burnt areas using ISODATA unsupervised classification

The models developed for burnt area and burn severity will be also applied in cooperation with Democritus Institute in new case studies selected in Italy and Greece.

3.4 Weather-based global forecasting model of wildfire emission (FMI)

3.4.1 Meteorological data sets and methodology used in model development

The following data sets are being used in the model development: SEVIRI/MSG Fire Radiative Power Pixel and Cloud Mask for the fires and clouds and ERA-Interim re-analysis data for the meteo. In addition, as supporting data, MODIS MOD14 and MYD14 Level 2 collection 6 are also being used for fires.

Our objective is to develop a weather-based prediction model to forecast emissions from wildfires to be employed in AQ forecasting simulations. The target area is the whole globe. The formalism of the model rests on a phenomenological framework.

In the model the whole globe is split into equal-sized and evenly-spaced areas of the size 1.44 degrees squared. Each area is parameterized according to the corresponding areal characteristics. The current parametrization is developed for African fires and is based on the remotely-sensed fire and cloud data by the SEVIRI geostationary instrument. Temporal resolutions of the model are 15 minutes for SEVIRI products and 3 hours for weather. The SEVIRI data are also checked against more accurate but scarce FRP data by the two MODIS orbital instruments, Aqua and Terra.

In the newest version of the prototype, the temporal FRP prediction arises from three components: weather function and annual and diurnal bell-like FRP curves composed of the logistic growth and decay. The annual FRP curve defines not only the period of fire season but also takes care of the difficulties that arise from the lack of detailed knowledge about the non-weather reasons for the occurrence of fires. It works as a reference curve and sets somewhat reasonable estimates for the shapes of the diurnal FRP curves, which are further fine-tuned by the weather conditions in the form of the weather function that employs the Grassland Fire Danger Index.

3.4.2 Results

The current prototype shows promises in predicting emissions from grass fires in highly fire concentrated areas in Africa (see Figs. 3.9 and 3.10), but it is still yet to be seen how it will work, for example, in the case of forest fires in much less fire concentrated areas in Europe. The orange curve in Fig. 3.11 shows a weather-based prediction of our model. All figures 1-3 represent the same area (grid cell) sized 157.83 km x 160.30 km with the center point at 18.00 degrees of longitude and -9.36 degrees of latitude in Angola, Africa.

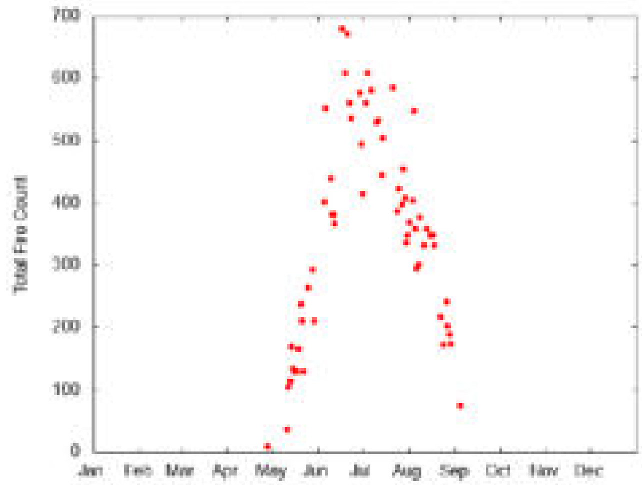

Fig. 3.9: Total daily fire counts of the year 2010 in the area defined in the text.

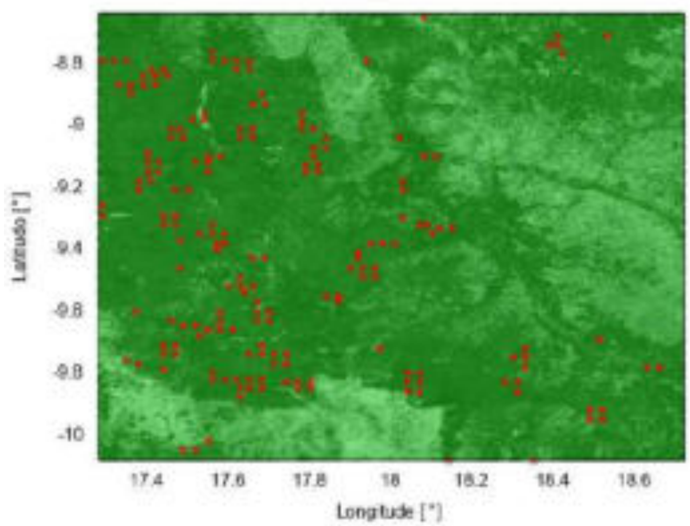

Fig. 3.10: An infrared snapshot of Angolan grass fires (184 pcs. of red asterisks) observed by SEVIRI on the 5th of June 2010 at 1315 p.m. (LT).

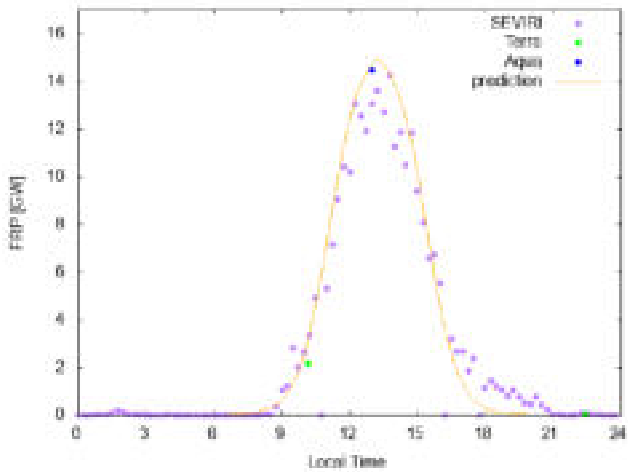

Fig. 3.11: Diurnal FRP of Angolan grass fires observed by SEVIRI, Terra, and Aqua instruments on the 5th of June 2010. The orange curve is a weather-based prediction of our model. The horizontal axis is in the 24 hour clock format.

4 Statistical analyses and modelling of trends in fire risk and fire occurrence

4.1 Comparison and testing of various fire danger monitoring methods over the Czech Republic (GCRI)

Comparison and testing of various fire danger monitoring methods over the whole Czech Republic (and Slovakia) at 500 m resolution for period 1961-present was performed and trends in fire danger was assessed; the methodology used and results of the analyses are presented in this report.

4.1.1 Methods used for fire danger assessment

Various fire danger rating systems have been developed in different parts of the world where forecasting of fire danger is crucial. Most commonly used fire danger rating systems are shortly described in the text bellow.

<u>Fire Weather Index (FWI) system</u>

FWI system was initially developed for conditions of boreal forests in Canada when it provided a means of evaluating severity of fire weather conditions in a standardized forest type (Wotton, 2009). Today, it is one of the most widely used fire danger rating systems, especially in Europe (including Mediterranean region) and North America. The FWI system is a part of the Canadian Forest Fire Danger Rating System (CFFDRS) and provides rating of fuels moisture in important fuel layers and several outputs describing fire behavior (Wotton, 2009).

Forest Fire Danger Index (FFDI)

The FFDI (McArthur, 1967) is widely used in Australia for forecasting the influence of weather on fire behaviour. The FFDI is a key tool for assessing fire danger in Australia (Dowdy et al., 2009). Fire managers and authorities in Australia use the regular FFDI forecasts published by the Australian Bureau of Meteorology.

Finnish Fire Index (FFI)

Another index used in Europe for forecasting fire danger is FFI. FFI system is basis for evaluating forest fire hazard in Finland. The Finnish Meteorological Institute (FMI) operationally monitors conditions favorable for forest fire potential.

For all three indices (FWI, FFDI and FFI), the soil moisture was fed from the Czech national drought monitoring system using daily estimations from SoilClim model (Hlavinka et al., 2011). SoilClim is a water balance based model that uses basic meteorological inputs measured in-situ, as well as information about soil and land cover. SoilClim is routinely used as a tool for drought monitoring for the area of the Czech Republic. Model provides estimates of soil moisture content in two layers of the soil profile (www.intersucho.cz).

All three applied fire danger forecast methods (FWI, FFDI and FFI) provide a numerical index that increases with fire danger and that is expressed as a fire danger scale. Canadian FWI uses 5 classes from very low to extreme (from 0 to 29 and more). Australian FFDI uses 5 classes from low to extreme (0 to 50 and more). Finnish FFI has 6 classes from very wet to very dry moisture conditions (from 1 to and 6).

Different levels of index comparison

The performance of FWI, FFDI and FFI indices was compared at different spatial and temporal levels. Firstly, performance of indices over whole area of the Czech Republic was analysed. It was done for the part of the growing season when vegetation is most prone to fire ignition. This period was divided into two parts – from April to June and from July to August. Fire danger intensity was assessed over the period 1956–2015 while four different land use types were taken into account.

One of possibilities how to evaluate performance of fire danger indices is to relate their values with real fire activities, even though it has certain limitations. Therefore, as a second step, the analysis of three fire danger indices versus wildlife fire events for the period 1991–2015 was performed. The analysis was undertaken for the area of the Czech Republic focusing on the part of the growing season from April to September. The total number of wildlife fires during analyzed period comes from the Fire Rescue Service of the Czech Republic (http://www.hzscr.cz).

Thirdly, the performance of FWI, FFDI and FFI was conducted specifically for the Bzenec area in the Jihomoravský kraj (the south-east part of the Czech Republic) where the fire event occurred in May 2012. The actual fire event of pine forest occurred there during the period 24th–30th May 2012. It was the largest forest fire event recorded in recent years in the area of the Czech Republic with 174 hectares of forest burned.

Moreover, the special focus was aimed at the year 2018 with its warm and dry spring and summer in comparison with the long term weather characteristics (http://portal.chmi.cz). Three fire danger indices were compared with forest fire events that occurred during the period from January to the end of September. Data of forest fire occurrence were obtained from the Fire Rescue Service. Indices and fire events were analyzed over the area of the Jihomoravský region that is considered as the warmest and driest region of the Czech Republic (M Trnka et al., 2016). The study of Trnka et al. (2018) showed that probability of days with very high fire danger is in this region double in comparison with the rest of the country.

4.1.2 Results and Discussion

Fig. 4.1 shows the order of years according to a percentage of the area that is under high risk of fire based on FWI, FFDI and FFI during the period 1956–2015. The order is contrived for four different land use types over the Czech Republic (arable land, grassland, deciduous trees and coniferous trees) for two parts of the growing season – from April to June and from July to August. For the period of April–June, we can mark years 1976, 2000, 2003 and 2007 as clearly standing out for all land use types showing that they were affected by high risk weather. For the period July–August, the most significant years with high risk weather are 1971, 1990, 1992, 1994, 2003 and 2015. According to fire risk weather, the most exceptional year for all land use types was definitely 2015. Especially for the period July–August, FWI and FFDI marked often the same years that were the most significant regarding the area under high risk. The area under high risk of fire is much larger during the period July–August than during April–June period with highest percentage achieved for arable land.

To make the study more complex, a comparison of three fire danger indices and wildlife fire events over the Czech Republic was contrived. The comparison was done for the period 2001–2015 with focus on the part of the year from April to September (Fig. 4.2). Figure 4.2 A shows the course of fire danger indices together with the number of wildlife fire events occurring through the period 2001–2015. The figure shows that values of all three indices correspond with fire event occurrence quite well even though FFI performs higher values than FWI and FFDI obtaining similar values. The FFI peaks over the value 2.5 while values of FWI and FFDI are over 2 at their maximum. All the three indices correspond well for high occurrence of fire events in 2003, 2007, 2011, 2012 and 2015 showing the highest values for 2003 and 2015 when drought spells and intensive heatwaves appeared in the Czech Republic and surrounding countries. Figure 4.2 B, C and D show the relationships between mean values of fire danger indices and the number of wildlife fires through the period April–September during 2001–2015. Scatterplots reach the R^2=0.77 for FWI and FFDI, and the R^2=0.59 for FFI. Figures clearly show that there is a clear and significant relationship between fire danger indices and a number of wildlife fires recorded by the Fire Rescue Service.

Figure 4.3 focuses on the performance of fire danger indices (FWI, FFDI and FFI) in the Bzenec area that was effected by a fire event of pine forest in 2012. The performance was conducted for the period 1st March–31st July 2012, or DOY (day of year) 61–213. The actual fire event occurred during the period 24th–30th May 2012 (DOY 145–151). The period of the fire event is represented in Fig. 4.3 by the green rectangle. From 20th (DOY 141) to 26th May (DOY 147), indices exceed value 4 nearly for all days. This period lasts for FFI till 27th May (DOY 148). Until the end of the period of the fire event, indices do not reach higher values than 3, only FWI reaches value 4 but only for one day (30th May, DOY 151).

The special focus was on the year 2018 and the area of the Jihomoravský region. In Figure 4.4, three fire danger indices are compared with forest fire events occurring from January to September of this year (DOY 1–263). At the beginning of the year, forest fires ignited rather rarely but from the end of February (from 21st of February, DOY 52) fire frequency increased. Especially FFDI was able to capture this period quite well. From the beginning of April (starting 8th of April, DOY 98), fire frequency increased even more – often with 2 or more fires per particular day. The large number of forest fires ignited in particular at the beginning of April. Then, at the end of June, the period with higher amount of fire events started and lasted to the beginning of September. Starting on 2nd of July (DOY 183), there was the forest fire event nearly every day. This period lasted until 29th of August (DOY 241). Largest number of forest fires was recorded on 8th of April, 21st of June and 23rd of August (DOY 98, 172 and 235) when 7 fire events ignited in the Jihomoravský region.

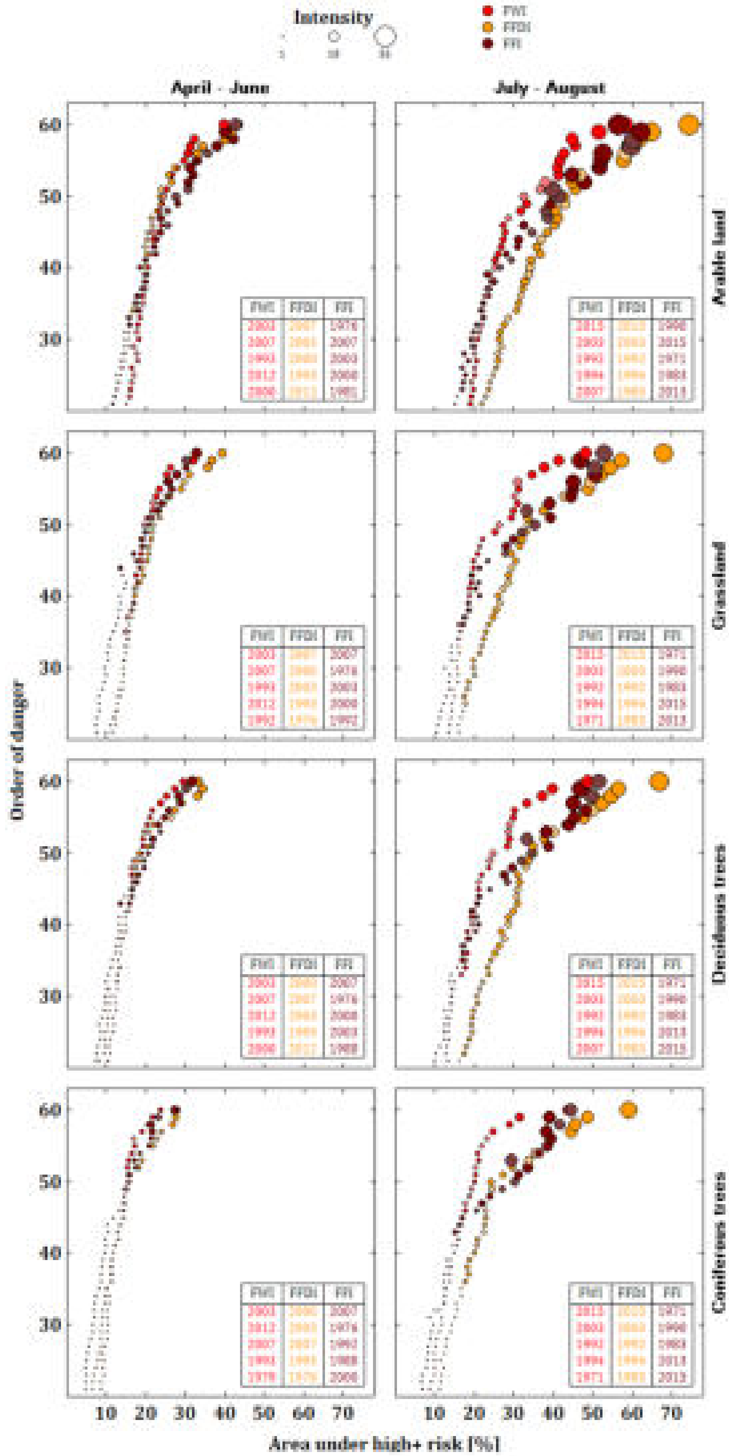

Fig. 4.1 Order of years according to the area under high risk of fire based on FWI, FFDI and FFI. Order is performed over the territory of the Czech Republic during the period 1956–2015. Table in lower right corner indicates the top five years according to the area affected by fire conducive weather. The territory is divided according to the four main land use types.

Fig. 4.2 (A) Fluctuations in the areal mean of fire danger indices (FWI, FFDI and FFI) and the total number of wildlife fires over the Czech Republic for the period April–September during 2001–2015; (B, C, D) The correlation of fire danger indices versus wildlife fire events over the Czech Republic for the period April–September during 2001–2015.

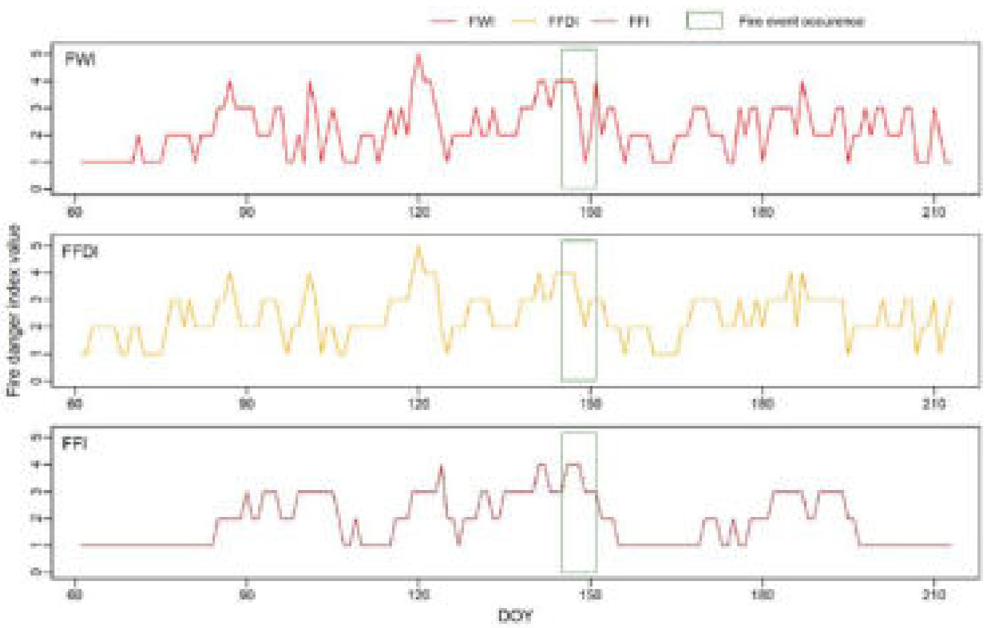

Fig. 4.3 Performance of fire danger indices (FWI, FFDI and FFI) in the Bzenec area where the fire event of pine forest occurred in May 2012. The comparison was conducted for the period 1st March–31st July 2012 (DOY 61–213). The green rectangle represents a period of fire event occurrence in Bzenec (DOY 145–151).

Occurrence of forest fires during this period corresponded well with values of fire danger indices, especially around days when more forest fires ignited. Correspondence of fire events with indices was most significant during days with 5 and more fires per day. During these days, fire danger indices often reached values between 3 and 4. FWI and FFDI often showed similar performance while FFI performed in many cases differently and reached rather lower values. The exception was 23rd of August (DOY 235) when 7 fire events were recorded – FFI value was 4.5 while FWI and FFDI were 3.9 or 4, respectively.

Comparison of fire danger indices with real fire events seems to be the useful way how to calibrate different tools of fire danger forecast, even though it has certainly some weak points and limitations. The biggest weak point and limitation is the fact that big percentage of fires is human-introduced and only a small portion of fires is caused naturally, e.g. by lightening (as mentioned e.g. by Vajda et al., 2014). Therefore, comparison of indices with fire events occurring on particular days can be biased and inaccurate, especially in areas close to cities, human settlements and recreation areas.

Since an increase in the number of fire danger is very probable in future climate conditions, it is essential to continue in developing of already existing tools for the forecasting of fire danger. It is necessary to adjust these tools to given local conditions and preserve proper accuracy. Though, the utilization of various methods for particular area and time can be in many ways quite challenging. One of challenges is that certain methods can require meteorological parameters that are not usually measured at meteorological stations. As an example, we can take Finnish FFI. The components of radiation balance are needed in the calculation of potential ET that is part of the FFI equation. However, these parameters are not always easily available from routine weather observations.

So far we have been able to analyse only forest fire due to the constraints in the database access. The special focus was given to fire weather conditions of the year 2018 in the Jihomoravský region. This region was chosen due to its climatic characteristics prone to fire ignition in comparison with other regions of the Czech Republic. Even though comparison between forest fire events and indices showed interesting results, more detailed research is needed to fully understand mutual relationships. In this study, fire danger indices were compared only with forest fires and not with all fires occurring in the landscape. Comparison of index values with all wildlife fires could help us see this problematic in a new light because the Jihomoravský region is typically agricultural region with not so high percentage of forested areas. However, these data will be available only during 2019.

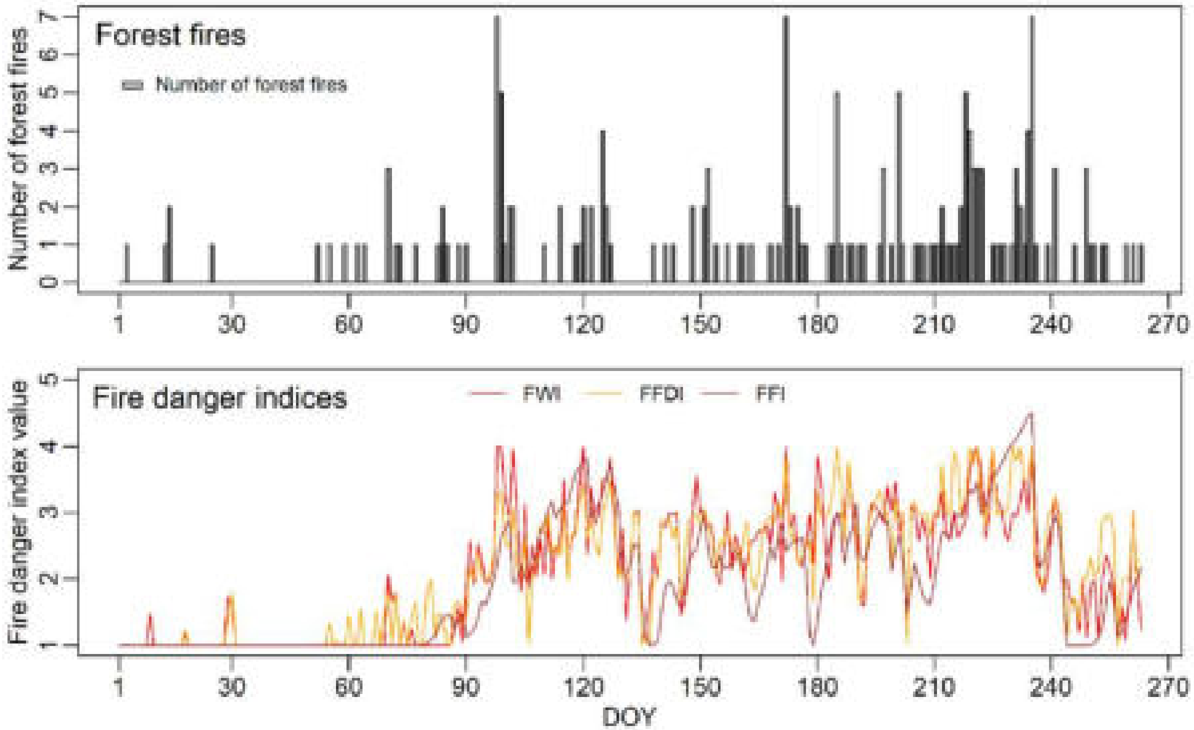

Fig. 4.4 The occurrence of forest fire events in the Jihomoravský region and areal means of fire danger indices (FWI, FFDI and FFI) for the period 1st January–20th September 2018 (DOY 1–263).

NOTE: The results are presented as peer-reviewed research paper submitted in January 2019, by authors Miroslav Trnka, František Jurečka, Martin Možný, Jan Balek, Zdeněk Žalud, affiliation Global Change Research Institute, Academy of Sciences of the Czech Republic, v.v.i, Bělidla 986/4a, 603 00 Brno, Czech Republic.

4.2 Climate attribution studies to extreme forest fire events (KNMI)

4.2.1 Data set and methodology used in model development

The datasets used are the ERA-Interim reanalysis (Dee et al. 2011), climate model simulations from EC-Earth (Hazeleger et al. 2011) and from CESM1-LENS (Kay et al. 2014).The methodology we use is similar to those in other climate attribution studies. First we study the case study using observations and reanalysis products. Then we define the event in a spatial and temporal coherent way to reflect its impact. Next, we assess the return times of the event using extreme value statistics. Using climate model simulations of previous, current and future climate we can assess whether the likelihood of such an event has / will increase or decrease relative to pre-industrial climate.

4.2.2 Results: case study Sweden 2018

We apply this methodology to the forest fires of July 2018 in Sweden. The manuscript describing the results in currently in preparation (Krikken et al., in prep.). Here we list the general conclusions. We find that the maximum forest fire risk in July 2018 had return times of ~15 years in Svealand, ~20 years in Gotaland and ~40 years in Norrland. Further, we find a negative trend of FWI for Svealand and Gotaland for the 1979 to 2017 time period, yielding a decreased risk of such an event solely based on reanalysis data. Note however that the uncertainty herein is large, owing to a relative short observational record and large natural variability of the FWI. The 2 large-ensemble climate models (EC-Earth and CESM1-LE) point to 2 to 3 times increased risk for such an event in all three regions for a 20C warmer climate, relative to pre-industrial. For the current climate relative to pre-industrial climate we find no clear response, where CESM1-LE points to a slight decreased risk of such an event but EC-Earth to a slight increased risk of such an event.

4.2.3 Future work

We aim for another analysis for recent extreme forest fires in the Mediterranean region, including the severe forest fires in Greece, Portugal and Italy over recent years.

5 Modelling drought and fire risk at seasonal and sub-seasonal scale

5.1 Seasonal statistical empirical forecasting system of the monthly drought code (KNMI)

5.1.1 Data set and methodology used in model development

For the empirical statistical forecasting system of the monthly drought code (MDC) we use multiple observational datasets. The MDC is constructed from monthly maximum temperature (Berkely Earth Database) and monthly precipitation. We use the dataset from Berkely Earth Database, for monthly precipitation (the Global Precipitation Analysis Products of the Global Precipitation Climatology Centre, GPCC). The main predictors are climate indices (NINO34, PDO, AMO, etc) which are available in the KNMI climate explorer.

The model is based on multiple linear regression for producing probabilistic forecasts of monthly drought code across the globe. The global CO2-equivalent concentration is taken as the primary predictor; subsequent predictors, including large-scale modes of variability in the climate system and local-scale information, are selected on the basis of their physical relationship with the predictand. The forecasts are made in the beginning of the fire season, and then updated monthly. Verification of the forecast is done through cross-validation.

5.1.2 Results

The model is currently being developed. It is based on the empirical forecasting system described in Eden et al. (2015). Seasonal empirical forecasts of the monthly drought code will be publicly available on the KNMI Climate Explorer (climexp.knmi.nl).

5.2 Seasonal fire danger forecasts for the Mediterranean region, Greece (NCSRD)

5.2.1 Methodology and datasets used in model development

According to the WP3 scheduled work, series of seasonal fire danger forecast maps will be computed and analysed for the fire seasons 2018, 2019 and 2020 for Greece. These seasonal maps will be evaluated based on the fire activity in the envisaged area and period of time. The meteorological data needed for the calculation of FWI parameters of the Canadian System CFFDRS are produced from high resolution simulations with the WRF model (v3.5.1).

During the first phase of this work, NCSRD calculated and evaluated a series of seasonal forecasted maps of meteorological fire danger, for the fire season (May-October) 2018, for Greece, using the Fire Weather Index (FWI) system.

The meteorological data needed for the calculation of FWI are produced from high resolution simulations with the WRF model (v3.5.1), for a period of six (6) months, using a grid spacing of 5x5 km covering the whole country. WRF-ARW model (version 3.5.1) has been suitably parameterized for high resolution production medium-term (seasonal) forecasts for Greece.

Initial boundary conditions for the WRF model simulations, were determined by twelve-hour analyses provided by the Climate Forecast System of Environmental Prevention, at 00 and 12 UTC for the time period of interest (National Center for CFSv2, Saha et al., 2010, 2013).

Five components of FWI System (Canadian CFFDRS) that account for the effects of fuel moisture and wind on fire behaviour, are calculated and investigated for the referenced period, namely, Drought Code (DC), Fine Fuel Moisture Code (FFMC), the Initial Spread Index (ISI), Fire Weather Index (FWI) and Daily Severity Index (DSR). The above referenced indices are calculated for every day of the fire season. Subsequently, a two-week map is calculated from the mean value of the maps of fifteen (15) days, which constitutes a representative, final map for each index. The maps are calculated at the beginning of the fire season and for its entirety. Depending on the FWI system parameter, the maps are provided at three time levels as 15-days, monthly and seasonal forecasts.

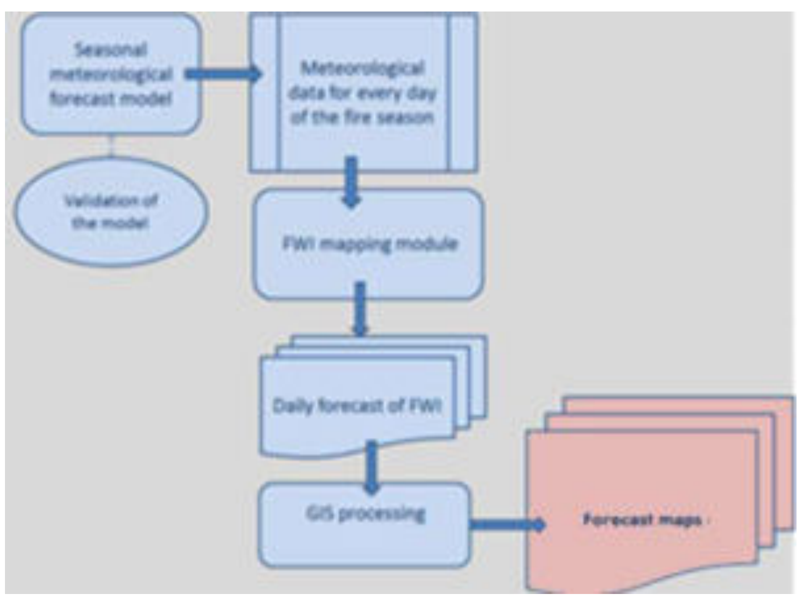

Fig. 5.1 Methodology of calculation of seasonal forecast maps.

5.2.2 Results

A number of maps were estimated from the daily forecast maps of FWI parameters, in order to validate the model and to evaluate the results, in collaboration with the end-users, for pre-operational use. Examples of these maps which are available in ARCGIS Grid-Ascii and in various georeferenced image (e.g. Tiff, jpeg) formats, are presented below.

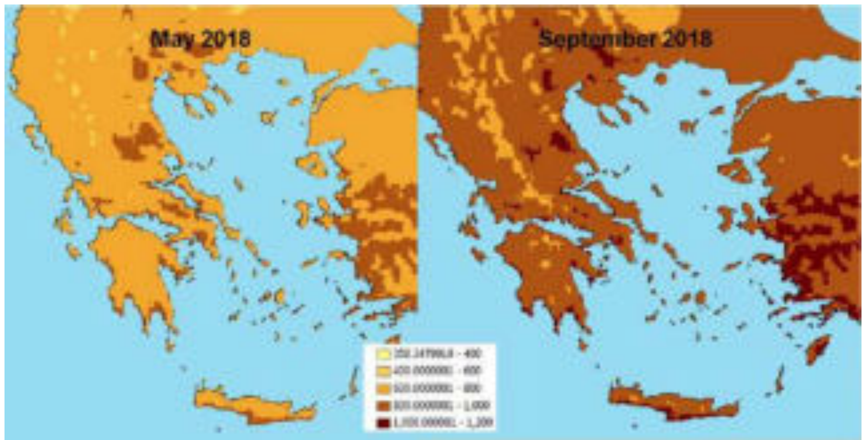

Fig. 5.2 Monthly Drought Code forecast maps of the 2018 fire season.

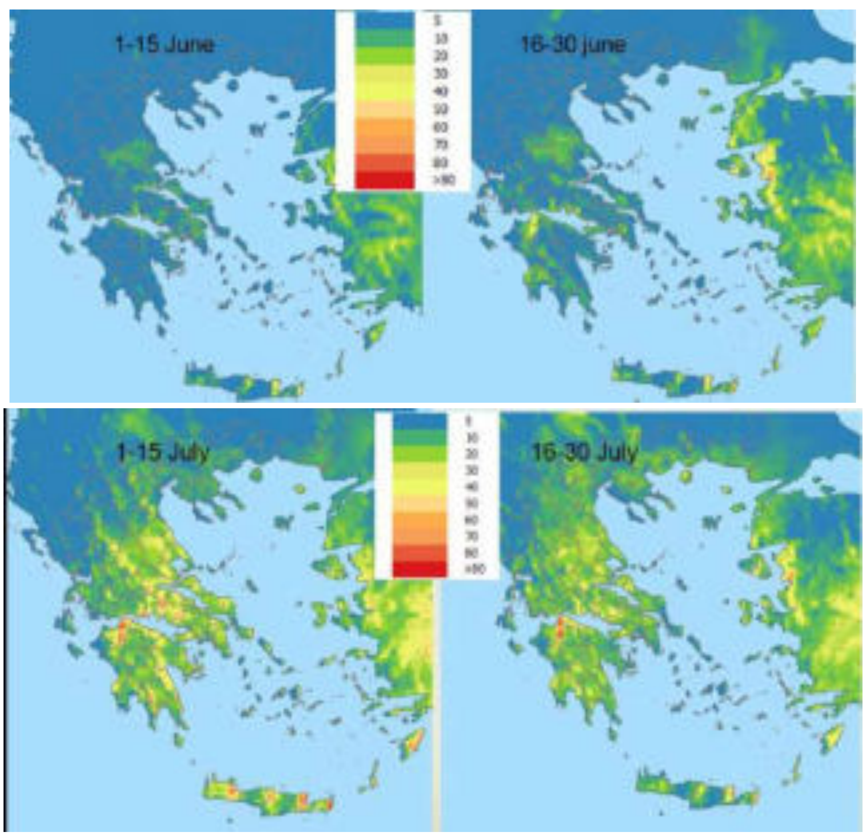

Fig. 5.3 15-days Severity Rating forecast maps of fire season2018.

Fig. 5.4. Significant fire events (locations, burned areas and date of ignition) of the 2018 fire season (source of fire data: EFFIS system).

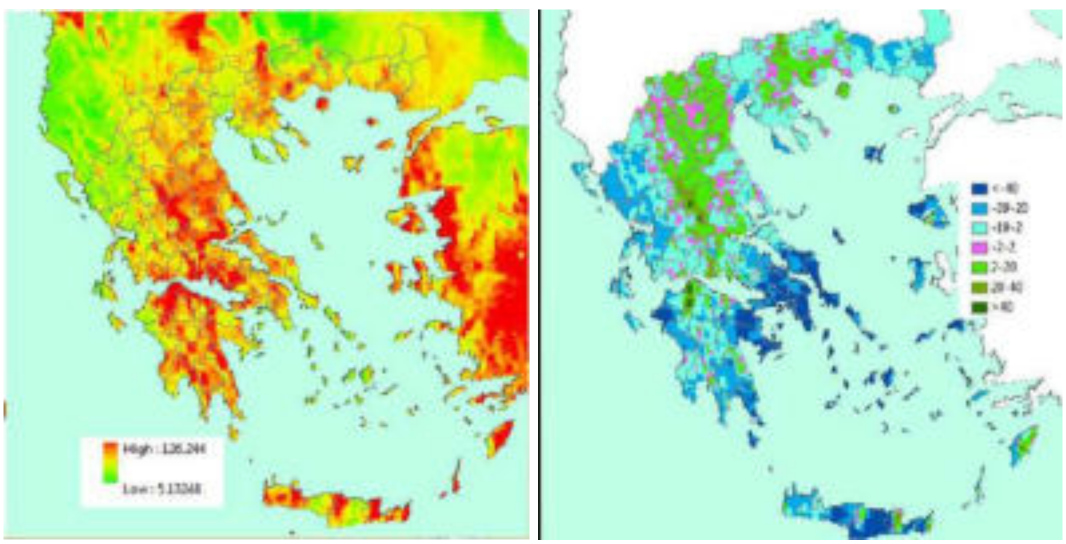

Fig. 5.5 (left) 90th FWI percentile for each cell in the study area estimated for the 2018 fire season, (right) Deviation of seasonal forecast FWI 90th percentile values (2018 fire season/May-September) from the FWI Extreme Class Thresholds map of Greece.

5.2.3 Plans for model applications: case studies, demonstrations with the users

The High Resolution Seasonal Forest Fire Danger mapping, using WRF forecasts, will be applied in Greece for all the fire seasons during the SERV_FORFIRE project. The resulting maps for the

2018 fire season have been evaluated, based on the fire events and the daily fire danger maps, provided by the Greek Civil protection Agency. This work is ongoing and it is expected that the forecast maps of 2019 and 2020 will be a basis for a systematic collaboration with the end-users, for further evaluation of the proposed methodology for fire risk mapping, as a tool for forest fires prevention and preparedness planning.

5.3 Drought climate service and seasonal forecasting for the Mediterranean region, Tuscany (CNR-IBIMET)

5.3.1 A customizable Drought Climate Service for supporting different end users'needs

One of the main issues to cope with drought is the temporal gap existing between the onset and development of a dry period, and the response in managing drought-related emergencies. In this context, it is crucial providing scientifically based technical support able to deliver timely, ready-to-use and reliable information in order to increase readiness, response and recovery capabilities.

IBIMET-CNR has developed a Drought Climate Service (DCS) in order to turn scientific advances in drought monitoring and forecasting, into operational information and services useful to decision makers with different needs (Magno et al. 2018). This design and development effort is supported also by the SERV_FORFIRE project.

The DCS is a process-based, multipurpose and multi-user operational service that does not necessarily need strong technical capacities to retrieve and use data and information. It is based on interoperable services and open-data concepts, and on the integration of different climate-based and satellite-derived data sources. In fact, it includes several climate-related products and tools such as monitoring indices, seasonal forecasts, WebGIS, RESTful Web Services. The system is expandable and customizable, thanks both to the involvement of local users to identify their priorities, and to the availability of targeted information specifically produced for agriculture and environmental monitoring.

The DCS is an open source web platform that guarantees a continuous and on-demand service to several local users, from decision makers or water authorities, who can ask at any time updated information related to a specific index or periods more useful for their assessments, to researchers, that need data for their further investigations, and even in other geographical areas covered by the available datasets.

5.3.2 The Drought Observatory

The operational chain implemented to calculate drought indices and to deliver final products is based on automatic and semi-automatic procedures. The Spatial Data Infrastructure (SDI) built to support the Drought Observatory (DO) [active url: https://drought.climateservices.it/en/] is based on the concept of Open Innovation, that consists of three pillars: Open Source, Open Data and Open Access. Moreover, the SDI responds to some fundamentals requirements: research data openness, interoperability, flexibility, scalability, responsiveness and specific user needs. Our user-oriented and process-based DO SDI is focused on the best use of climate and environmental data for drought assessment and their translation in information, instead of simple data sharing.
The DO SDI technological components (Fig. 5.6) are organized in typical client-server architecture and interact from the data provider's download data process to the results representation to end users, following general OGC guidelines.

OGC Standards: OGC (Open Geospatial Consortium) standards are used in several elements developed into the DO SDI, starting from the data model, designed using Unified Modelling Language (UML) (ISO TC/211), to PostGIS open source software.

Data Model: the data model is developed following a participative approach among the researchers involved in data collection and analysis for the application schema implementation.

Platform Interoperability: to ensure the platform interoperability between geospatial data and services, three main services are considered in the general SDI architecture: catalogue service, data service and processing service.

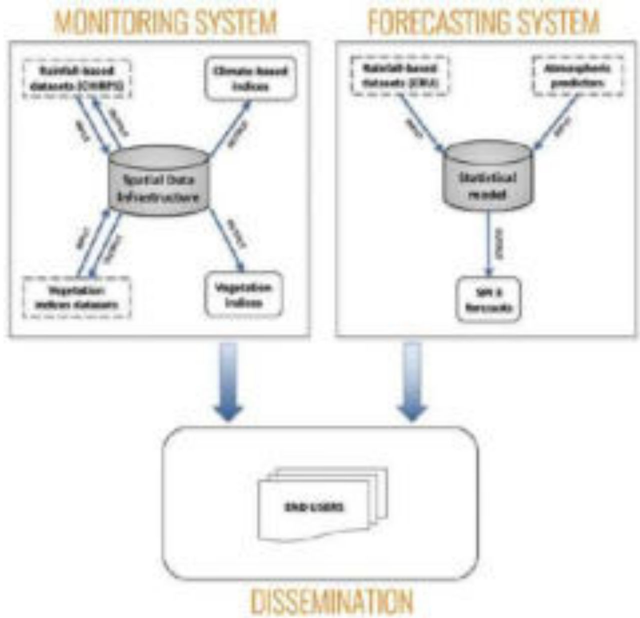

Fig. 5.6 Drought Observatory components scheme.

5.3.3 The DO Spatial Data Infrastructure concept and design

- Providers Layer Retrieving input data
- Drought Framework Layer Managing metadata and processing stored data
- Client-side Layer Results dissemination

All the three layers communicate through specific Representational State Transfer (REST) web services, following the Service Oriented (SOA) paradigm (Fig. 5.7). REST paradigm, even if only marginally considered in the OGC standards implementation (i.e. for the WMTS), is preferred to the Simple Object Access Protocol (SOAP) because it is lightweight and less client-side complex to manage by the users. Furthermore, RESTful Web Services provide functions of data extraction and downloading in an effective and highly flexible way.

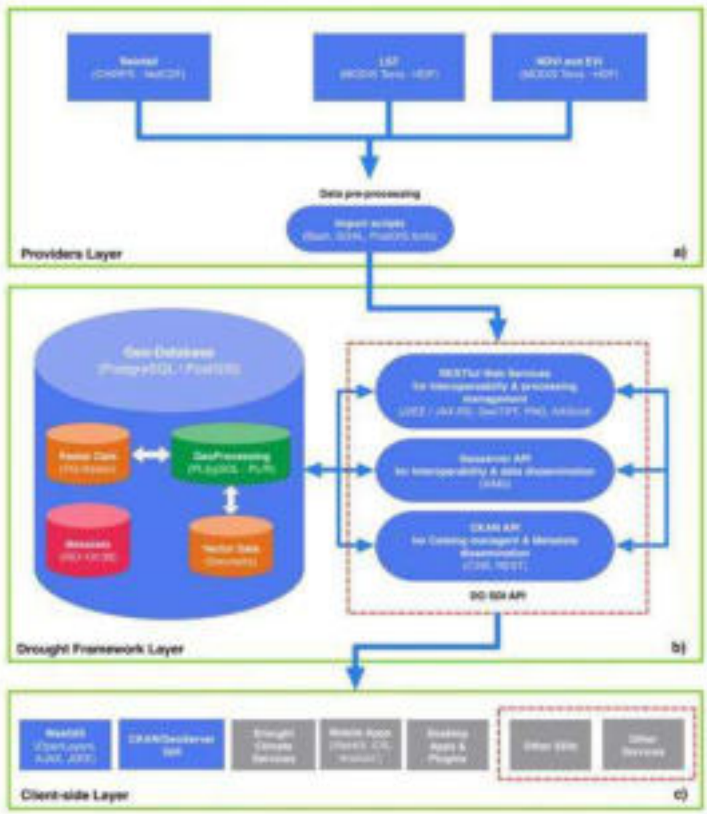

Fig. 5.7 DO - SDI design.

The Providers Layer (A)

It is in charge of managing input data coming from different sources (CHIRPS rainfall, and MODIS LST, NDVI, EVI) and storing them into the Geodatabase (GeoDB), implemented into the Framework layer. The OGC data formats actually supported by the DO SDI are the NetCDF for input CHIRPS rainfall dataset, and the Well-Known Text (WKT) for vectors used for the extraction and processing functions.

MODIS data are in Hierarchical Data Format-Earth Observing Systems (HDF-EOS) format, an approved standard recommended for use in NASA Earth Science Data Systems. Specific Bash scripts have been developed in order to download and prepare input data before saving them into the GeoDB.

Geospatial Data Abstraction Library (GDAL) and PostGIS reprojection, tiling and storing functions are used to improve the GeoDB performances and to harmonize the datasets with the data model.

All datasets are reprojected into a common and widely used reference system: the EPSG:4326 (i.e. Latlong, WGS84). The same Bash scripts call RESTful Web Services supplied by the Framework Layer to store the datasets into the GeoDB.

A continuous input data updating is ensured by cron daemon (crontab file) that launches the scripts automatically.

The Drought Framework Layer (B)

It is the main component of the DO SDI architecture, in which the PostgreSQL database represents the only environment for data storage and geoprocessing (Fig. 5.8). At this implementation stage, geoprocessing queries do not completely follow OGC WPS specifications, working with REST Web Services instead of SOAP. All the services allow the storage of new data while their retrieving and processing are developed locally using REST paradigm, and called through simple HTTP GET and POST operation requests. PostgreSQL is used to store input data (rainfall, LST, NDVI, EVI), to perform all geoprocessing procedures (queries, indices elaborations, statistical operations, etc.), and to generate intermediate data (LSTmin, LSTmax, NDVImin, NDVImax, EVImin, EVImax) and output images (SPI, TCI, VCI, E-VCI, VHI, E-VHI) with different formats, i.e. GeoTIFF, PNG, ASCII Grid. Though all the indices are calculated inside PostgreSQL, the different complexity of vegetation and rainfall indices computation has forced to use different libraries. TCI and VCI, in fact, result from simple arithmetic operations that can be done directly in PL/pgSQL using PostGIS library, successfully taking advantage of its features.

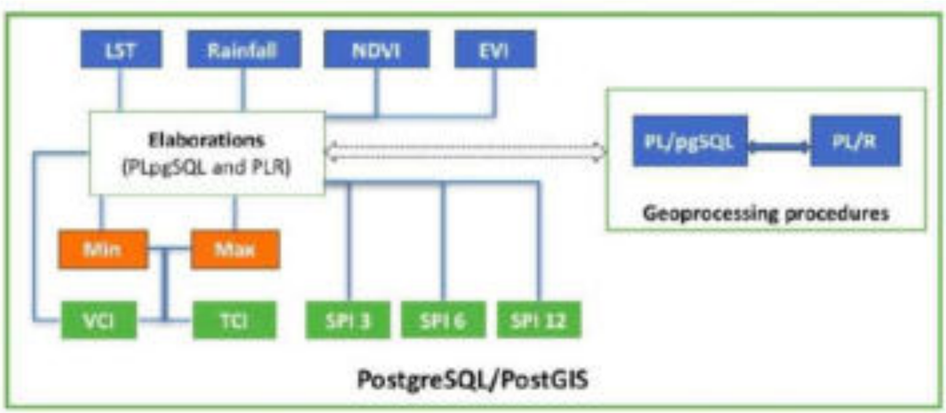

Fig. 5.8 The Drought Framework Layer.

The SPI index, instead, is obtained with more complex statistical functions (fitting of a Gamma probability distribution, transformed into a standard Gaussian variable). For this reason, SPI elaboration has been implemented with the integration of a specific R library with PostGIS library. The integration between R engine and PostGIS is made possible by PL/R, the R wrapper for PostgreSQL. The monitoring system is developed integrating state-of-the-art science and advances in technologies, and selecting a set of coupled rainfall-based and satellite-derived indices.

The indices selected take into account the following issues:

- types of drought
- availability of data

- consistency of data
- geographical characteristics
- time and spatial variability
- final users

Climate Based Indices

Precipitation, as the first and main parameter pointing out drought occurrence, is used in many indices, among which the most widespread Standardized Precipitation Index (SPI) and the less known Effective Drought Index (EDI). These indices are considered better than others as providing different time scales of drought occurrence, and detecting its variation and duration.

Vegetation Based Indices

These indices focus on vegetation health monitoring and are related to temperature and moisture stresses throughout a combination of NDVI or EVI, and LST parameters/indices. They represents an indirect drought responsive way to analyze the phenomenon, and satellite-derived indices are widely used for their spatiotemporal characteristics of full ground cover and quasi-continuous time observations.

The set of indices selected

Table 5.1 Available indices

TYPE	INDEX	INPUT DATA	TIME SERIES	TIME SCALES	SPATIAL RESOLUTION
Climate-based	SPI	Rainfall	From 1981	Multi monthly (3,6,12,24 months)	0.05°
Climate-based	EDI	Rainfall	from 1955	Daily	Point
Vegetation-based	TCI	LST	from 2000	8 days	1 km
Vegetation-based	VCI	NDVI	from 2000	16 days	250 m
Vegetation-based	VHI	TCI and VCI	from 2000	16 days	250 m
Vegetation-based	E-VCI	EVI	from 2000	16 days	250 m
Vegetation-based	E-VHI	TCI and E-VCI	from 2000	16 days	250 m

Predicting meteorological drought: the forecasting system is based on an empirical approach to predict meteorological drought using the SPI 3 index, few months in advance from large scale observed climate indices.

Estimating drought correlation with large scale drivers: a physically-based statistical approach using a Multivariate Regression model (MR) to predict future anomalies. This forecasting approach has 3 phases replicated for each grid cell of the spatial domain: 1) selection of predictors; 2) estimation of parameters; 3) extrapolation. In the first phase, we use a double step procedure to select the best MR model in terms of predictive performance, i.e. which are the large scale atmospheric drivers (and their lags) to use as predictors for SPI-3. In the second phase, we estimate the value of MR parameters that reproduce the linear relation between SPI-3 and each driver selected at 1). In the third phase, we use the parameter estimates obtained at 2) to predict future SPI-3 anomaly.

The SPI-3 dependent variable of the MR model is calculated using global CRU rainfall dataset (from 1901 to the present). For the SPI computation, which is done by using the "SPEI – R Package", the Pearson III distribution and the period 1961-2010 are used for standardizing the variable to a Gaussian distribution with zero mean and standard deviation of one.

Predictors are selected among observed atmospheric and oceanic climatic indices according to the list below, then they are centered and standardized by using the overall mean and standard deviation, respectively. The de-trending procedure is applied by monthly sub-setting each time series since an MR model is built for each forecast month. Furthermore, a maximum of five months leading up to the forecast SPI-3 are set for each predictor to be included in the design matrix of the regressors. For example, the design matrix of the SPI-3 model of March is composed of the predictors' timeseries from October to February, since the SPI-3 of March is computed by using the precipitation of March, April and May. The de-trending procedure is based on a local nonparametric regression and is applied to the dependent variable as well. Finally, 12 design matrices with 43 observations, that is, monthly values of the 1974–2015 time series, and $13*5$ predictors, are set, being 13 indices and five leading time steps. Then, a procedure of deletion has been applied in order to address the well-known issue of multi-collinearity in MR models by eliminating linear combinations as well as high correlation between explanatory variables. From this filtered design matrix, a double-steps procedure is applied to select the best model in terms of predictive performance:

(1) find the eight best models for each group of one up to 12 predictors according to the adjusted R2 index;

(2) find the best model among those identified at (1) by means of 10-fold cross-validation criterion and RMSE index. The entire procedure has been carried out at each grid cell of the spatial domain.

Table 5.1 Climatic indices used in the forecasting empirical model.

Climatic indices identified as possible predictors

PARAMETER	EXTENDED NAME	SOURCE	LINKS
AMO	Atlantic Multidecadal Oscillation	ESRL-PSD	https://www.esrl.noaa.gov
MEI	Multivariate ENSO Index	ESRL-PSD	https://www.esrl.noaa.gov
NAO	North Atlantic Oscillation	CPC	http://www.cpc.ncep.noaa.gov
SV-NAM	Seasonally Varying NH Annular Mode	HOK	http://www.bio.mie-u.ac.jp/
MZI	Modified Zonal Index	IRI-DL	http://iridl.ldeo.columbia.edu
MED-SST	Mediterranean SST, 1st EOF, 2nd EOF	CPC	http://www.cpc.ncep.noaa.gov
TRI-SST	Atlantic Tripole SST, 1st EOF	ESRL-PSD	https://www.esrl.noaa.gov
GUI-SST	Guinea Gulf SST, 1st EOF, 2nd EOF	IRI-DL	http://iridl.ldeo.columbia.edu
IND-SST	Indian Ocean SST, 1st EOF, 2nd EOF	IRI-DL	http://iridl.ldeo.columbia.edu
SISCI	Eurasian Snow Cover Extent	Rutgers GSL	https://climate.rutgers.edu

Table 5.2 Empirical seasonal model skill. In the table signif 0.05 and signif 0.10 represent the percentage of predictors in the best model that result individually significant at level α = 0.05 and α = 0.10 of the t-test, respectively. adjR² and RMSE range is the minimum and maximum value obtained throughout the spatial domain; the SPI range is the minimum and maximum value observed.

Evaluation				Predictive Performance		
MONTH	SIGNIF. 0.05	SIGNIF. 0.10	RANGE ADJR2	MONTH	RANGE RMSE	RANGE SPI
Nov	82%	92%	(0.52; 0.72)	Nov	(0.442; 0.694)	(-2.042; 2.546)
Oct	70%	84%	(0.24; 0.53)	Oct	(0.543; 0.782)	(-2.196; 3.130)
Sep	65%	79%	(0.30; 0.55)	Sep	(0.629; 0.879)	(-2.375; 2.614)
Aug	68%	83%	(0.29; 0.74)	Aug	(0.523; 1.235)	(-6.528; 2.801)
Jul	42%	62%	(0.16; 0.39)	Jul	(0.839; 1.297)	(-3.917; 5.940)
Jun	63%	82%	(0.48; 0.68)	Jun	(0.529; 0.632)	(-3.256; 2.485)
May	77%	86%	(0.49; 0.74)	May	(0.444; 0.769)	(-3.727; 2.547)
Apr	60%	76%	(0.30; 0.61)	Apr	(0.601; 0.938)	(-3.853; 2.589)
Mar	87%	94%	(0.61; 0.79)	Mar	(0.350; 0.632)	(-2.260; 2.581)
Feb	69%	85%	(0.36; 0.71)	Feb	(0.531; 0.797)	(-1.960; 3.623)
Jan	52%	71%	(0.18; 0.56)	Jan	(0.611; 1.042)	(-2.007; 5.349)

5.3.4 Model evaluation and predictive performance: summary of the results

An evaluation of the predictive performance of the best model for each SPI-3 is done, summarizing the results obtained in each grid cell. The great number of values above 0.50 reveals generally a good model definition. This behavior is more pronounced during winter season, when drought can be more critical. Lower performance was identified in summer period, when dryness events are common and thus have weaker impacts.

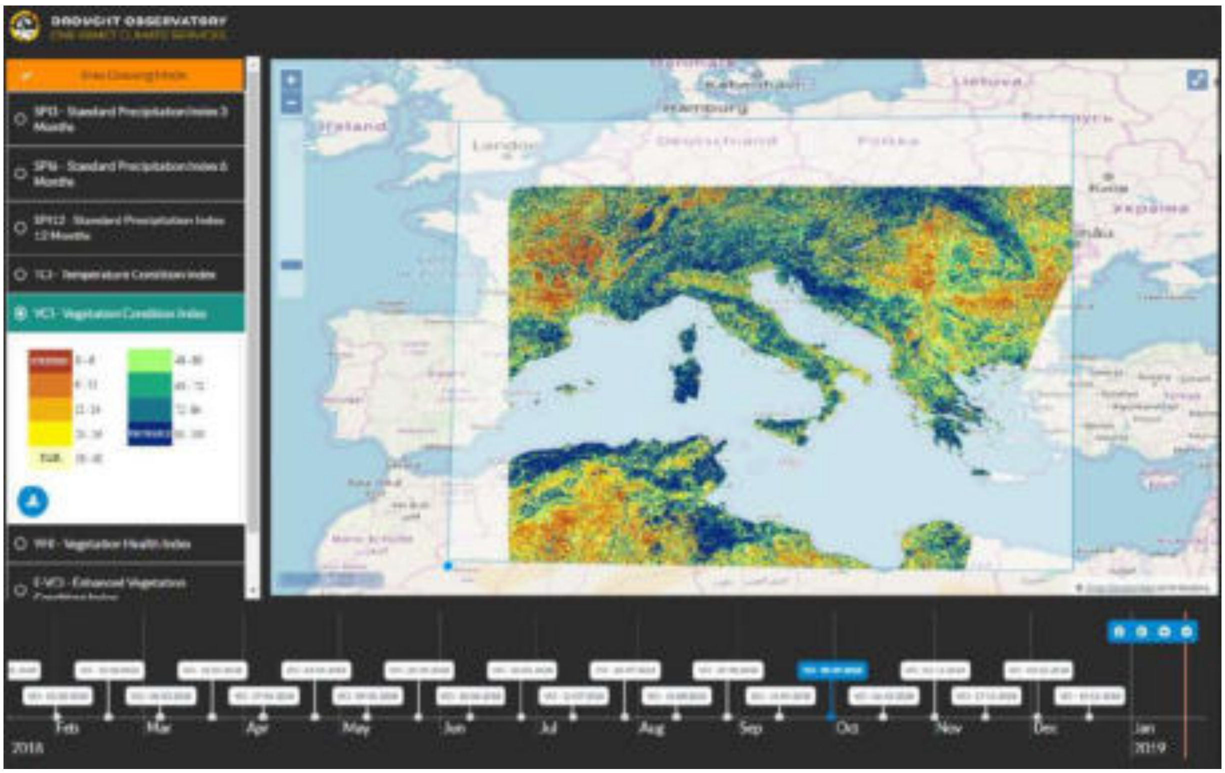

Fig. 5.9 The WEB-GIS portal.

A WebGIS application based on open source solutions customized to integrate different datasets and share maps of drought indices with researchers, decision makers and other stakeholders is available at the address: [WEB GIS DROUGHT](https://droughtsdi.fi.ibimet.cnr.it/dogui/) [url: https://droughtsdi.fi.ibimet.cnr.it/dogui/]

5.4 Modelling forest fire danger at seasonal and sub-seasonal scale for boreal forest conditions – Finland (FMI)

5.4.1 The current operational forest fire danger forecast in Finland

In Finland, FMI operationally monitors conditions favourable for forest fire potential and issues public forest fire warnings when the numerical index describing the fire danger exceeds a certain threshold. Since summer 1996, the estimation of forest fire potential has been based on the Finnish Forest Fire Index (FFI), which is operationally determined by estimating the volumetric moisture of a 60 mm thick soil surface layer (Venäläinen and Heikinheimo 2003, Vajda et al. 2014). Monitoring of soil moisture starts after the snowmelt in spring and ends in September. Fire danger forecasts are made 48 hours ahead using as input numerical weather prediction data and are disseminated to the emergency authorities twice a day, at 06 and 18 UTC. Fire survey flights are planned by the fire-fighting authorities based on the fire index values received (Vajda et al. 2014). In addition to forest fire danger, grass fire danger is also monitored calculating the volumetric soil moisture of a 30 mm thick soil surface and disseminated to the fire rescue authorities especially after snowmelt when the forests are still wet but the grass debris from previous summer are already dry and very flammable.

Extending the range of forest fire risk assessment products with seasonal and sub-seasonal products will allow rescue services and authorities to prepare well in advance for the expected risk and plan the fire survey flights. In order to assess the applicability of the seasonal and sub-seasonal forecast in forest fire danger assessment in Finland a statistical model was developed and will be evaluated.

5.4.2 Meteorological datasets and methodology used in model development

The input data needed in the development of the model for seasonal and sub-seasonal forest fire risk forecasting included in-situ observations, such as air temperature (T), precipitation rate (RR) and relative humidity (RH) from the Finnish station network interpolated onto 10*10 km^2 grid, and volumetric soil moisture of the 60 mm thick soil surface layer calculated for the same grid size as the meteorological parameters. All the input variables used were from 12 UTC except precipitation, for which daily accumulated values were required in the model development. The time period used was 2003-2016 being limited by the availability of FFI in FMI archives. FFI is used in the operational forest fire risk forecast and warning system by FMI. It is a physically-based soil surface moisture estimation method employing as input traditional surface observations, numerical weather forecast model fields and weather radar measurements. The fire danger indicator and the fire danger forecast and warning system has been described in details by Vajda et al. (2014).

The seasonal and sub-seasonal re-forecast data used in the computation of forest fire danger for the whole Finland was provided by ECMWF SEAS5 system and ECMWF ENS system respectively. SEAS5 is the newest ECMWF's fifth generation seasonal forecast model providing broad overview of the atmospheric evolution for the 7-month or even 13 month period (Johnson et al., 2018). It runs at 36 km grid resolution as a 51 member ensemble, having land-atmosphere and ocean-atmosphere coupling. The forecast are initialized on the 1st of each month. Re-forecasts or hind-casts are also produced on the 1st of every month for years 1981 to 2016, thus they can be compared to historical records for calibration purposes. They consists of 25 ensemble members and have the same variables as the operational forecast (ECMWF 2017). We used air temperature, dew point from 12 UTC and daily accumulated precipitation values in the production of seasonal forest fire danger for the time period 2010-2018 and run the predictions for a maximum of 3-month lead time starting in April and ending in September. Relative humidity, needed as input parameter in the statistical model was calculated from dew point temperature and 2 m temperature similarly as in Bedia et al. (2017).

ECMWF's extended range forecast system (ENS) predicts the weather conditions for the time range of 10 up to 46 day and run twice a week, on Mondays and Thursdays. The ensemble consists of 51 members of which one control forecast and 50 forecasts with perturbed initial conditions. The horizontal resolution of the forecast is 0.4° (~36 km) and there are 91 vertical levels. Re-forecasts are based on an 11-member ensemble of 46-day ENS integrations, starting on the same calendar day as the real time forecasts for the past 20 years. The parameters and time period used in extended range fire danger prediction were the same as for the seasonal forecast covering the fire season, April-September.

The Finnish Forest Fire Index (FFI) used in the operational and short range warning system is determined by the volumetric moisture of a 60 mm thick soil surface layer calculated from potential evaporation computed from air temperature, air humidity, wind speed and radiation, and precipitation data (Venäläinen and Heikinheimo 2003). The volumetric moisture is scaled to range between 1 and 6, with 1 indicating the lowest and 6 the highest possible fire danger in terms of fuel moisture. An FFI value of 4.0 corresponding to a volumetric moisture of 20% is the threshold value above which fire hazard warnings are issued. All the calculations are made using a 3 h time step.

A statistical model was developed to estimate the FFI for seasonal and sub-seasonal scale. In order to decide which meteorological parameters to include in the statistical model a cross validation (CV) using the validation set approach was first performed against FFI. The CV was performed on a station data set consisting of 3-hour data from four different stations (Helsinki-Vantaa, Jokioinen, Jyväskylä and Sodankylä) for the summer season 1971 to 2014 (April to September). Different meteorological parameters (2m temperature, relative humidity, precipitation and wind) and parameter combinations were included in the CV. Finally, the wind was as a result of the CV neglected from the statistical model.

The model was developed in two different phases, performing a linear regression first on the station data set and further extended to the gridded data set for the whole country. The interpolated gridded data (V=volumetric soil moisture (12 UTC), T = 2m temperature (12 UTC), RR = daily accumulated precipitation and RH = relative humidity (12 UTC)) for time period 2003 to 2015 (summer season: April to September) was used as input data in the final statistical model:

$$\log(V) = aT + bRR + cRH + d$$

The constants were determined by least-square fitting to the data; a = -0.3005, b = 0.0029, c = 0.0091 and d = 5.3334. Thus the FFI was determined from the volumetric soil moisture (Vajda et al., 2014).

5.4.3 Results

The developed statistical model was tested for both seasonal and sub-seasonal time-scales using ECMWF's re-forecast data: SEAS5 System with an ensemble of 25 members and ENS System with an ensemble of 10 members. In this report climate outlooks of FFIs for summer season 2010 are presented as an example for potential products. For both seasonal and sub-seasonal time scales, the computed FFIs are lower in the northern part of Finland than in the southern part (Fig. 5.10 and Fig. 5.13), which is in line with the observed FFIs.

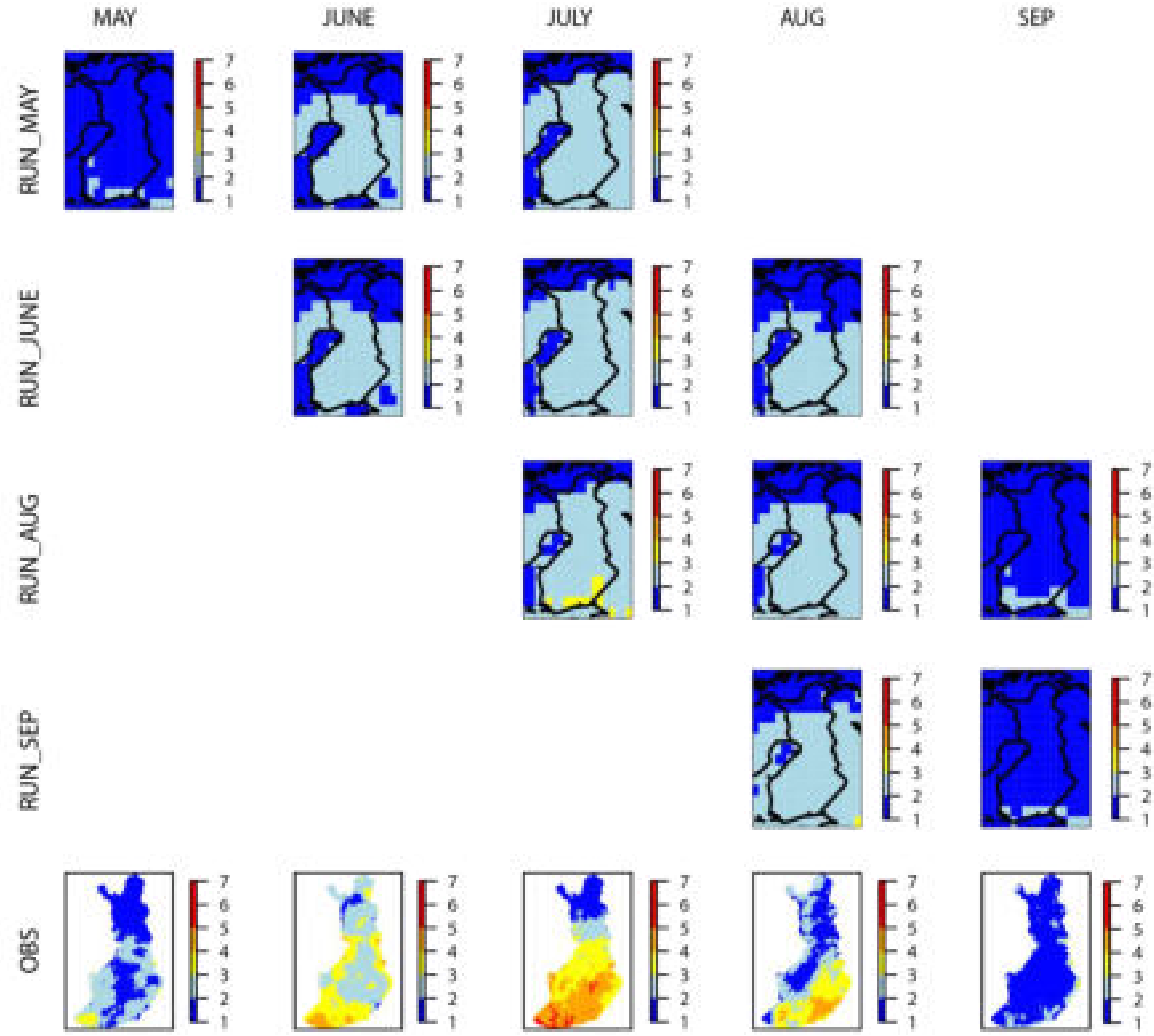

Fig. 5.10 Forecasted (rows 1 to 4) and observed (row 5) monthly mean FFIs for summer season 2010. Rows represent model run initialized in the beginning of each month, columns represent runs with different lead time. FFI values above 4 indicate fire risk conditions

When compared with observed FFI values (Fig. 5.11) a significant underestimation of the fire risk by the statistical model can be observed for both time-scales, this being more pronounced, showed in lower FFI values, in the monthly outlooks. The underestimation can be a resulted by the low skill of the developed statistical model itself or by the low skill of the input re-forecast data (Fig. 5.12). Thereby, a thorough validation of the model and the input parameters needs to be done during spring 2019. As expected, the runs with 1 month lead-time and 1-2 weeks respectively in case of extended range forecast, produced more reliable results.

The sub-seasonal runs only result in a small area of fire risk (FFI>4) for one of the investigated weeks, although the observed FFI values indicate areas with fire risk for all of the weeks (Fig 5.13).

Compared to the seasonal runs, the sub-seasonal timescale runs indicate more promising results for FFI forecasting.

As mentioned above the computed seasonal FFI values do not show any indication of forest fire, which was observed in June, July and August. The highest calculated FFI values (FFI =3) are achieved in July in southern part of Finland, but this does not still exceed the forest fire risk threshold.

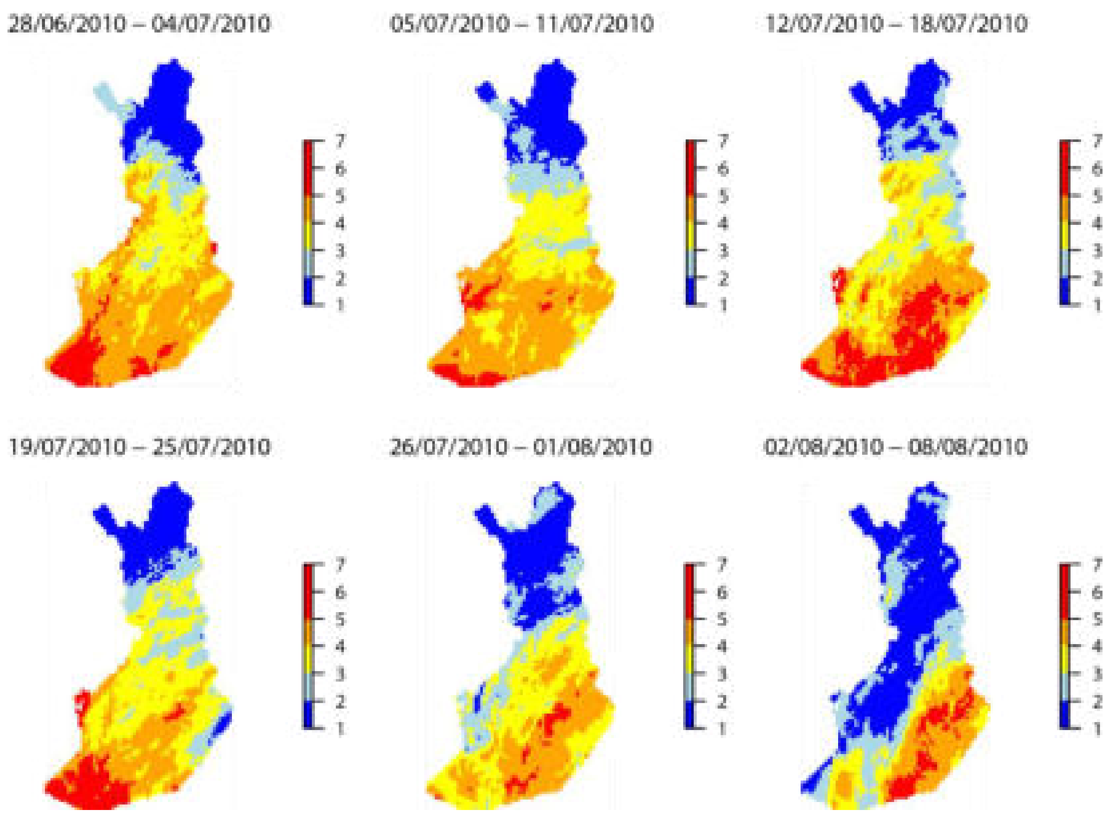

Fig. 5.11 Observed weekly means of FFI. FFI values above 4 indicate fire risk conditions.

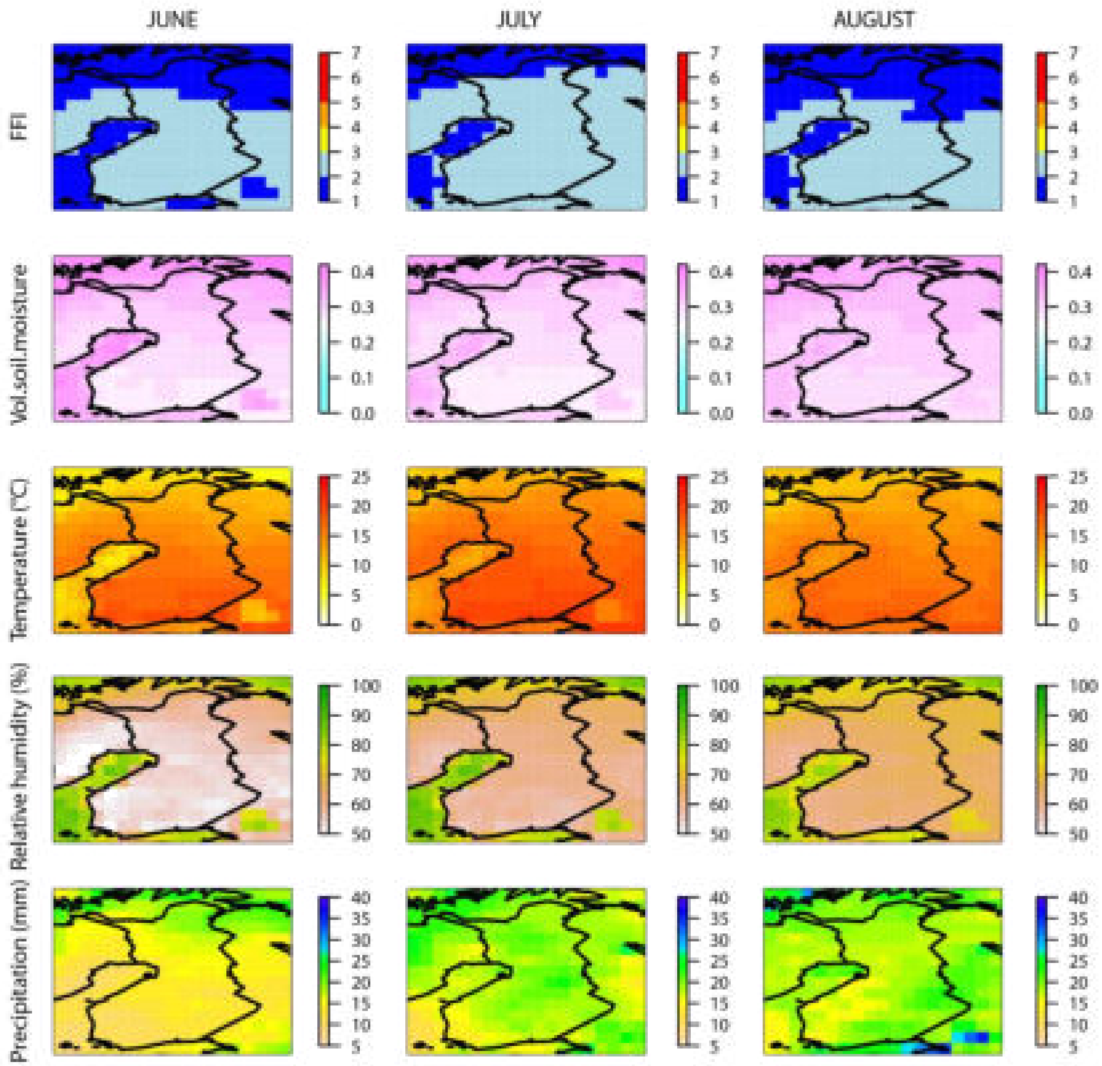

Fig. 5.12 Forecasted FFI (row 1) and volumetric soil moisture (row 2), and the used input parameters from ECMWF's SEAS5 reforecast run from 1 of June 2010 with three month lead time (June 1 lead-month, July 2-lead month, August 3 lead-month).

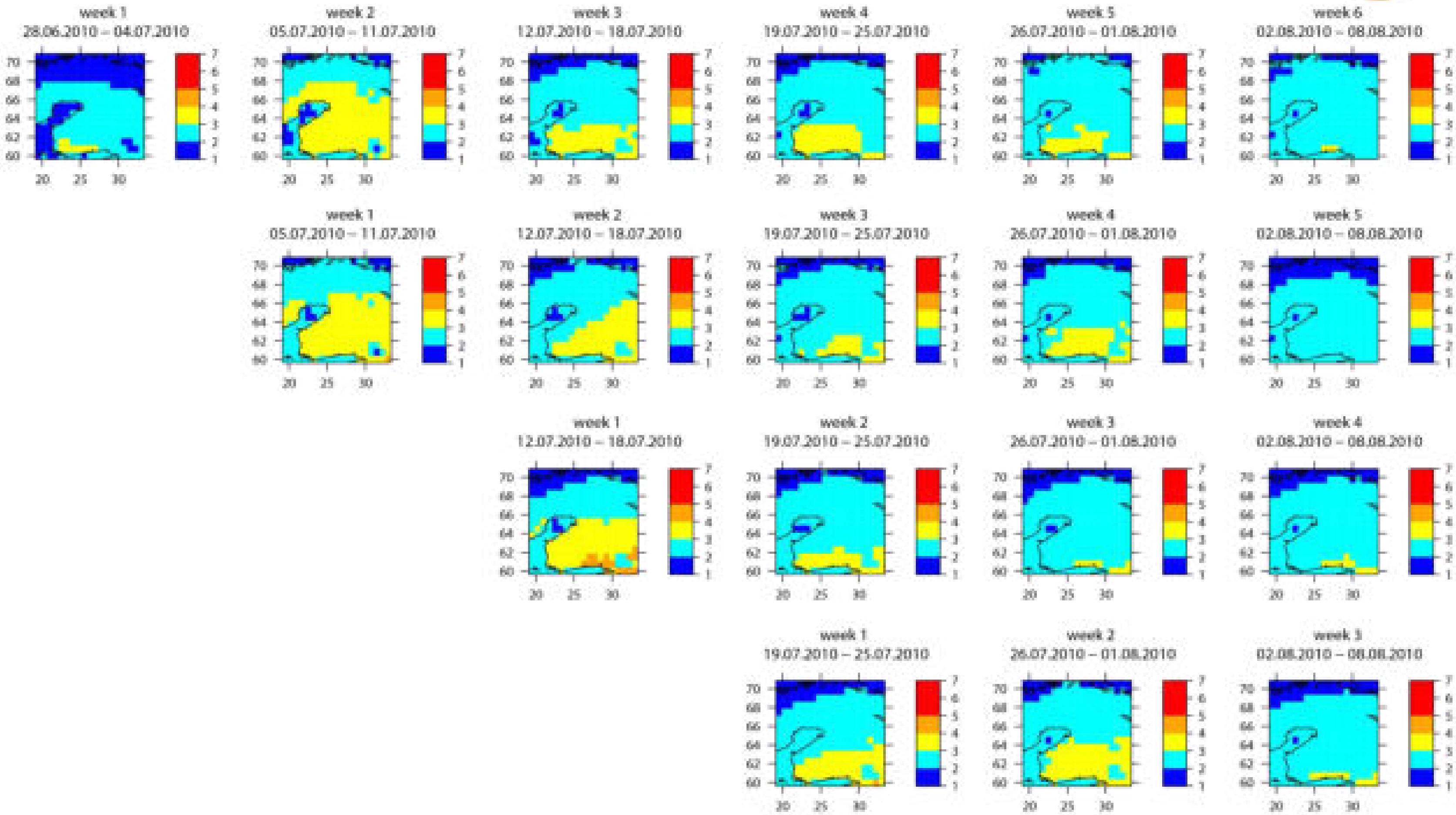

Fig. 5.13 Six-week climate outlooks of FFIs during summer 2010. Rows represent different model runs, columns represent different lead time. FFI above 4 indicate fire risk conditions.

5.4.4 Plans for model applications: demonstrations with the users

Validation of the model run results will be performed during early 2019 using the runs for the fire seasons of 2017-2018 and using standard verification methodology. Both seasonal and sub-seasonal (6 week) outlooks will be evaluated against observed FFI archived in FMI covering the whole Finland.

Following verification, the demonstration of the developed monthly and 6 week forest fire danger outlooks will be performed during the fire season 2019. The outlooks will be produced for the whole country and iterated with the involved end-users, i.e. Rescue services from Eastern Karelia and Regional State Administrative Agency (AVI) from Northern Finland who are going to test them in the preparation of fire survey flights. The amount communicated products, sub-seasonal and/or seasonal might vary according to user's requirements.

6 Concluding remarks

A set of models and statistical approaches have been developed and described in this report in order to model and/or forecast fire risk and occurrence, fire burnt area, fire expansion, fire emission, drought and fire risk forecasting at for estimating drought and fire danger at diverse temporal and spatial scale over Europe. The time frame covered ranges from daily to sub-seasonal, seasonal and climate projection scale. The models and methods developed are going to be tested and further applied within the framework of SERV_FORFIRE joint activities in the pilot area selected by the partners: the Basilicata region in Italy, Tuscany region in Italy and Eastern Attika in Greece. The forest fire danger forecasting model developed for boreal conditions will be produced for the whole Finland and tested by FMI together with the stakeholders. The approaches laboured for the analysis of various fire danger monitoring methods and estimation of trend for the future fire danger will be applied for Czech Republic. In addition estimation of trend for the future fire risk will be provided for Greece. The results gained from the applications performed with the models and statistical approaches and forecast systems developed will increase or understanding on the fire risk and fire activity and will serve fire management, planning and decision-making authorities in improving the preparedness and safety level of our societies and reduces the economic costs of wildfires.

7 References

Bedia, J., Golding, N., Casanueva, A., Iturbide, M., Buontempo, C., Gutiérrez, J.M, 2017: Seasonal predictions of Fire Weather Index: Paving the way for their operational applicability in Mediterranean Europe. Climate Services, Available from: http://dx.doi.org/10.1016/j.cliser.2017.04.001

Dee, D. P., S. M. Uppala, A. J. Simmons, P. Berrisford, P. Poli, S. Kobayashi, U. Andrae, et al. 2011. "The ERA-Interim Reanalysis: Configuration and Performance of the Data Assimilation System." Quarterly Journal of the Royal Meteorological Society 137 (656): 553–97. https://doi.org/10.1002/qj.828.

Dowdy, A.J., Mills, G.A., Finkele, K., De Groot, W., 2009. Australian fire weather as represented by the McArthur Forest Fire Danger Index and the Canadian Forest Fire Weather Index. CAWCR Technical Report 10. Centre for Australian Weather and Climate Research, Melbourne.

Eden, J. M., G. J. van Oldenborgh, E. Hawkins, and E. B. Suckling. 2015. "A Global Empirical System for Probabilistic Seasonal Climate Prediction." Geoscientific Model Development 8 (12): 3947–73. https://doi.org/10.5194/gmd-8-3947-2015

Hazeleger, W., X. Wang, C. Severijns, S. Ştefănescu, R. Bintanja, A. Sterl, K. Wyser, et al. 2011. "EC-Earth V2.2: Description and Validation of a New Seamless Earth System Prediction Model." Climate Dynamics 39 (11): 2611–29. https://doi.org/10.1007/s00382-011-1228-5.

Hlavinka, P., Trnka, M., Balek, J., Semerádová, D., Hayes, M., Svoboda, M., Eitzinger, J., Možný, M., Fischer, M., Hunt, E., Žalud, Z., 2011: Development and evaluation of the SoilClim model for water balance and soil climate estimates. Agric. Water Manag. 98: 1249–1261

Johnson S. J., Stockdale T. N., Ferranti L., Balmaseda M. A., Molteni F., Magnusson L., Tietsche S., Decremer D., Weisheimer A., Balsamo G., Keeley S., Mogensen K., Zuo H., and Monge-Sanz B. 2018: SEAS5: The new ECMWF seasonal forecast system, Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2018-228, https://doi.org/10.5194/gmd-2018-228

Joint Research Centre, EFFIS, Fire danger forecast, http://forest.jrc.ec.europa.eu/effis/about-effis/technical-background/fire-danger-forecast/

ECMWF, 2017: SEAS5 user guide, Version 1.1, available from:
https://www.ecmwf.int/sites/default/files/medialibrary/2017-10/System5_guide.pdf

Kay, J. E., C. Deser, A. Phillips, A. Mai, C. Hannay, G. Strand, J. M. Arblaster, et al. 2014. "The Community Earth System Model (CESM) Large Ensemble Project: A Community Resource for Studying Climate Change in the Presence of Internal Climate Variability." Bulletin of the American Meteorological Society 96 (8): 1333–49. https://doi.org/10.1175/BAMS-D-13-00255.1

Krikken, F., F. Lehner, I. Drobyshev, K. van der Wiel, GJ van Oldenborgh. In prep. “Attribution of the role of global warming in the forest fires in Sweden 2018.

Lasaponara R, Tucci B, Ghermandi L. On Use of Satellite Sentinel 2 Data for Automatic Mapping Burnt Areas and Burn Severity. 2018. Sustainibility 10 (11), 3889

Magno R., T. De Filippis, E. Di Giuseppe, M. Pasqui, L. Rocchi, B. Gozzini, 2018: Semi-automatic Operational Service for Drought Monitoring and Forecasting in the Tuscany Region. Geosciences. 8(2), 48: 1-25. https://doi.org/10.3390/geosciences8020049

McArthur A.G., 1967: Fire Behaviour in Eucalypt Forests. Department of National Development Forestry and Timber Bureau, Canberra, Leaflet 107

Saha Suranjana, et al., 2010: The NCEP Climate Forecast System Reanalysis. Bull. Amer. Meteor. Soc., 91, 1015-1057. http://doi.org/10.1175/2010BAMS3001.1

Trnka, M., Semerádová, D., Novotný, I., Dumbrovský, M., Drbal, K., Pavlík, F., Vopravil, J., Štěpánková, P., Vizina, A., Balek, J., Hlavinka, P., Bartošová, L., Žalud, Z., 2016: Assessing the combined hazards of drought, soil erosion and local flooding on agricultural land: a Czech case study. Clim. Res. 70: 231–249

Vajda A., Venäläinen A., Suomi I., Junila P. and Mäkelä H.M, 2014: Assessment of forest fire danger in a boreal forest environment: description and evaluation of the operational system applied in Finland, Meteorological Applications 21(4): 879–887, DOI: 10.1002/met.1425

Venäläinen A., Heikinheimo M., 2003: The Finnish forest fire index calculation system. In Early Warning Systems for Natural Disaster Reduction, Zschau J, Kuppers A (eds). Springer: Berlin; 645–648

Wotton M., 2009: Interpreting and using outputs from the Canadian Forest Fire Danger Rating System in research applications. Environmental and Ecological Statistics 16(2): 107-131