Wildfire Rapid Detection and Mapping and Post-fire Damage Assessment in Greece

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Abstract

The National Observatory of Athens (NOA) has been established in Greece as a research institute offering, among other things, operational Earth Observation services for disaster management of forest wildfires. In this paper, we present the main activities of NOA related to fire detection, fire monitoring and rapid mapping, along with damage assessment services using satellite remote sensing techniques supported by state-of-the-art information technologies. The focus lies in integrating fully automatic processing chains into dedicated systems that offer stakeholders online access to robust, accurate and fully operational Web-based tools to assist their Emergency Response and Emergency Support actions.

1. Introduction

Fires have been one of the main driving forces in the evolution of plants and ecosystems, determining the current structure and composition of the landscapes [1]. However, significant alterations in the fire regime have occurred in the recent decades, primarily as a result of socioeconomic changes, increasing dramatically the catastrophic impact of wildfires as it is reflected in the increase during the 20th century of both the number of fires and the annual area burnt.

Fire monitoring and management in Europe and in the wider Mediterranean region in particular, is of paramount importance. Almost every summer, massive forest wildfires break out across the Mediterranean, leaving behind severe destruction in forested and agricultural lands, infrastructure and private property, and losses of human lives. European initiatives in the area of Earth Observation (EO) like the GMES program have therefore undertaken an active role in the area of fire monitoring and management for Europe, and supported the development of relevant European operational infrastructures in the domain. Several pre-operational projects like RISKEOS and SAFER (Services and Applications For Emergency Response) have laid the ground for the main operational mapping component service GIO EMS, which started operations on April 1, 2012. It has a worldwide coverage and provides stakeholders with maps based on satellite imagery, rush (burnt area maps) and non-rush mode (post-wildfire assessment).

At the National Observatory of Athens (NOA), volumes of EO images of different spectral and spatial resolutions are being processed on a systematic basis to derive thematic products that cover a wide spectrum of Emergency Response and Emergency Support applications during and after wildfire crises, from fire detection, fire monitoring and rapid mapping, to damage assessment in the inflicted areas. The processed satellite imagery is combined with auxiliary geo-spatial information, including land use/land cover (LU/LC) and fuel data, administrative boundaries, road and rail network, toponyms, locations of interest, and meteorological data to generate and validate added-value fire-related products.

The operational EO activity of NOA in the domain of wildfires management is highly enhanced by the integration of innovative information technologies that have become available within the TELEIOS (EC/ICT) project. Through this collaboration, fully automatic processing chains have been developed, relying on: the effective storing and management of the large amount of EO and Geographic Information Systems (GIS) data, the post-processing refinement of the fire products using semantics, and the timely creation of fire extent and damage assessment thematic maps. These technologies are built on top of a robust and modular computational environment, to facilitate several wildfire applications to run efficiently, both for continuous disaster monitoring and on-request emergency mapping, such as real-time fire detection and monitoring, rapid burnt area mapping, detailed burnt scar mapping after crisis, and time series analysis of burnt areas for diachronic damage mapping and statistical analyses of fire history.

An overview of the fire services delivered by NOA is presented in the following sections.

2. Real-time fire monitoring

Most of the fire detection algorithms using data from the SEVIRI (Spinning Enhanced Visible and Infrared Imager) sensor on top of the Meteosat (MSG) series of geostationary meteorological satellites are based on variations of EUMETSAT's (the international organization managing the Meteosat platforms) proposed classification methodology for identifying hotspots [2]. NOA, among others [3], has adopted a similar approach [4] for detecting hotspots. However, different studies have been conducted [5] and validated [6] that suggest another direction. The main concern with respect to EUMETSAT's recommendation has to do with the variance of the solar contribution to Earth's apparent temperature, leading to unreliable comparison with predefined thresholds. Therefore, it is suggested that a contextual analysis should be carried out through a spatial matrix of N×N pixels. NOA, on the other hand, has adopted a dynamic threshold estimation approach, as opposed to fixed thresholding, to cope with the solar variance, leading to increased thematic accuracy [7]. It should be noted that [5] was applied in the framework of SAFER project with noticeable omission errors for Greece, mainly attributed to insufficient customization for the geographic area's special characteristics in terms of vegetation species and underlying land cover.

At a global level, operational fire monitoring systems are based on MODIS (Moderate-resolution Imaging Spectroradiometer) sensor data on top of the Terra and Aqua satellite platforms. The spatial resolution is four times better than that of MSG/SEVIRI (1×1 kilometers, as opposed to 4×4 kilometers, respectively), but with much less temporal resolution (four passes over Greece per day, as opposed to the five-minute acquisition resolution, respectively). The most prominent systems are the European Forest Fire Information System, maintained by the Joint Research Center, and the Fire Information for Resource Management System (FIRMS), delivering global MODIS hotspots and fire locations in easy-to-use formats, maintained by NASA.

Since 2007, NOA has operated an MSG-1,2,3/SEVIRI acquisition station and has been systematically archiving raw satellite images on a five- minute basis. Using these data, NOA has developed and has been sustaining a real-time, 24/7 fire hotspot detection service for effectively monitoring forest fires all over Greece in near-real time. Other main advancements include the establishment of a fully automatic processing chain for fire monitoring, and the enhancement of the thematic accuracy of the generated hotspot products using semantic technologies.

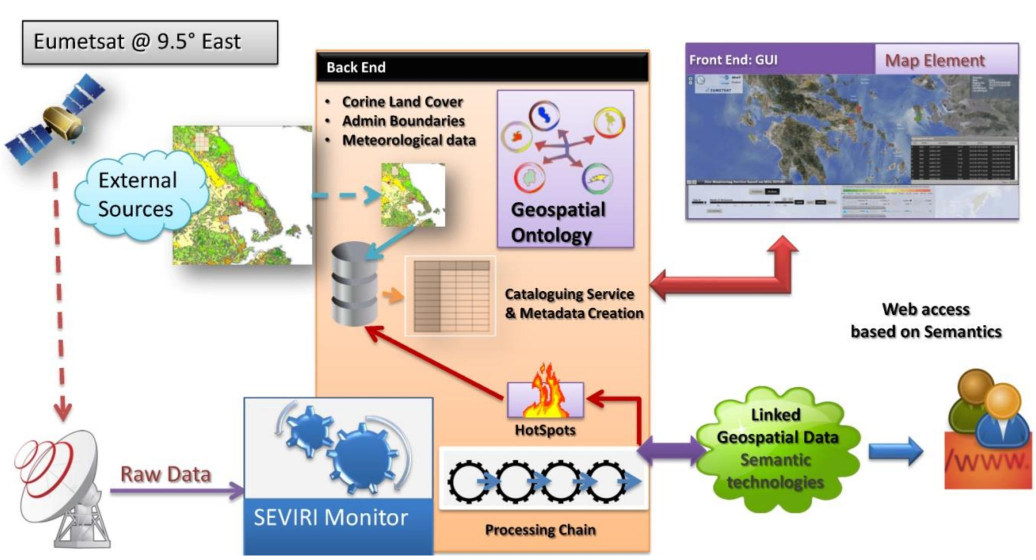

Figure 1. Fire monitoring service architecture. Image Credit: NOA

2.1 System architecture

The fire monitoring service architecture is depicted in Figure 1. The entire process is fully automatic, from raw image collection to final presentation to the user interface and storage of the hotspot products.

The ground-based receiving antenna collects all spectral bands from the MSG platforms. Then, the raw datasets are decoded and temporarily stored at the ground station before the application of a dedicated service, known as MSG SEVIRI RT Fire Monitoring, which manages the data stream in real-time, extracting and storing the raw file metadata in an SQLite database, filtering the raw data files and dispatching them to a dedicated disk array for permanent storage.

The same process is responsible for remotely triggering the processing chain [4] to derive hotspots. The back-end of the system implements the hotspot detection processing chain, evaluates semantic queries for improving the accuracy of the hotspot products and generates thematic maps. In this context, a geospatial ontology which links the generated hotspot products with stationary GIS data (Corine LU, Coastline, Greek Administrative Geography) and with linked geospatial data available on the Web (LinkedGeoData, GeoNames) is used to derive high-informative thematic products. Finally, dissemination to the end-user community (civil protection agencies, state and regional authorities, environmental agencies, public authorities, and private sector users) is realized through a Web application. Figure 2 shows a screenshot of the dedicated front-end Web interface.

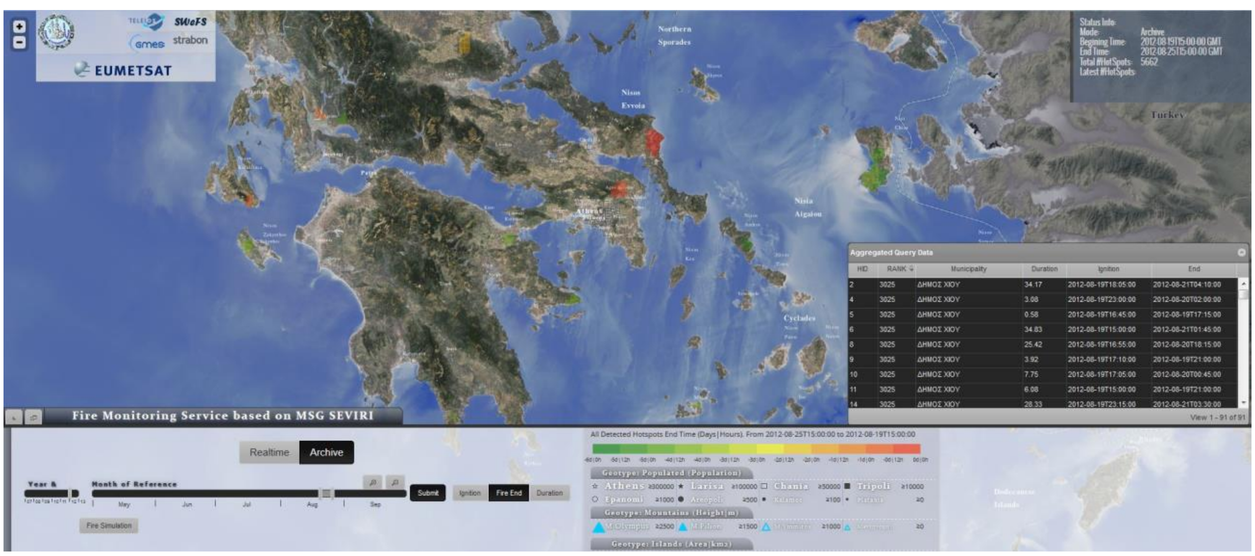

Figure 2. Web-tool for visualizing real-time and archived hotspots in Greece. Image Credit: NOA

2.2 Processing chain

The core processing chain [4] comprises of a series of sub-modules, initially responsible for ingesting the raw data from the native format to an appropriate one for the subsequent processing stages, and cropping of the image to the area of interest. Then, the cropped data are resampled to a rectangular grid and georeferenced using high-order transformation polynomials. The output product is fed to the classification module that uses the algorithm described in [2], where for each detected hotspot we associate a confidence level. The final stage concerns the output generation to shapefile and raster formats and storage of the hotspots in the system database.

The innovative aspect of the processing chain in the post-processing refinement phase, based on semantic technologies, has been implemented in the framework of the TELEIOS project and achieved the third prize in the International Semantic Web Conference (ISWC) conference [8]. According to this concept, a hotspot product is refined by analyzing its spatio-temporal persistence and pattern, and by taking into account the underlying LU/LC conditions and administrative boundaries.

Additionally, in order to cope with the ~3.5 kilometer low spatial resolution of the MSG/SEVIRI sensor – a trade-off with its very high temporal resolution – we have integrated fuel data with meteorological data (wind direction), and altitudinal zone information to map the active fire occurrence probability at each timestamp on a sub-pixel level.

To this end, the original hotspot pixel has been split to a 7-by-7 rectangular pixel grid aimed at achieving a ~500 meter\-wide cell. At this point, an iterative analysis is invoked for attributing to each of the 49 bins of the grid a probability of active fire occurrence that depends on the underlying fuel type, the confidence level of the initial hotspot observation, the contribution of the neighboring bins in fire transmission inside an area of 3-by-3 bins wide, which is a variable of the wind direction and the fuel characteristics of the area, and the expected relations, as deduced from the diachronic analysis of fires [9] between the fire occurrences on the one hand, and the altitudinal zones, the slope and the aspect characteristics of the affected areas on the other.

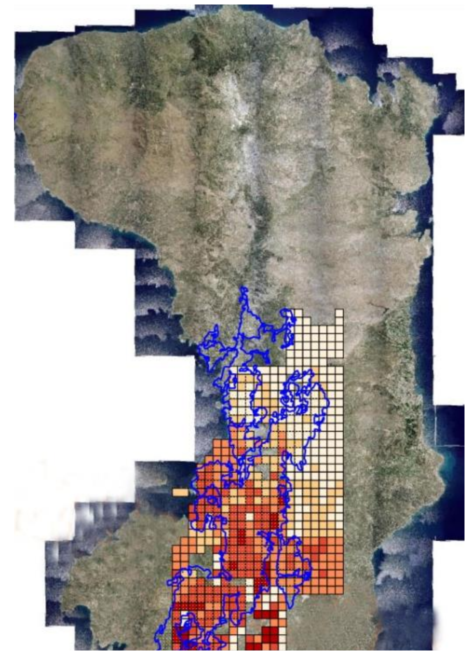

Figure 3. Increasing resolution for MSG/SEVIRI hotspots using LU/LC and meteorological information. Image Credit: NOA

Figure 3 depicts the probability distribution in these bins weighted in the range 1-10, for the severe wildfire that struck the island of Chios in August 2012. Red bins correspond to higher fire occurrence probability, and white to lower. The blue line corresponds to the delineated burnt area after the fire, based on the use of high resolution satellite data (Landsat ETM+).

2.3 Evaluation of thematic accuracy

Evaluating the thematic accuracy of the real-time fire monitoring products is not a straightforward task, as it entails the cross-validation of the hotspot products with ground-truth data. The latter is impossible to acquire using accurate in-field information. Therefore, we adopted another approach by estimating the relevant thematic accuracy of the MSG/SEVIRI hotspot products with respect to a similar EO application using MODIS. Evaluation of the thematic accuracy of the hotspots derived from the NOA processing chain were estimated for three full days, from Aug. 24-26, 2007, when Greece was struck by the most severe forest wildfire in 20 years. The corresponding MODIS hotspots products that served as the reference dataset were collected by the NASA portal FIRMS.

The analysis produced estimates for the relative omission error and false alarm rate of 11 percent and 27 percent respectively, which are adequate for the intended service. The slightly elevated relative false alarm rate is attributed to the inherent discrepancy in the spatial resolutions of the two sensors and the increased temperature sensitivity of MSG/SEVIRI near intense wildfires. The false positives do not occur at isolated regions, but instead near neighboring pixels detected as fires by both the MSG/SEVIRI and MODIS sensors. This might be the outcome of hot smoke fumes and carbon dioxide concentrations in the atmosphere from nearby fires that contaminate neighboring pixels.

3. Burn Scar Mapping and damage assessment applications

Remote sensing tools for the accurate, robust and timely assessment of the damages inflicted by forest wildfires provide crucial information to public environmental agencies and related stakeholders before, during and after the crisis. In literature, several types of EO datasets have been used, ranging from moderate resolution systems like AVHRR and MODIS [10], to higher-resolution imagery from Landsat TM sensor [11], and very-high-resolution data including Formosat, Worldview, Ikonos, Quickbird, and Worldview [12]. Additionally, several techniques have been applied, indicatively using support vector machines [13], texture-based feature extraction methods [14], fixed thresholding and classification tree approaches [15], along with multi-temporal analysis [16].

NOA has developed a fully automatic single and/or multi date processing chain [15] that takes as input satellite images of any spatial and spectral resolution and produces precise diachronic burnt area polygons and LU/LC damage assessments over the Greek territory.

3.1 Emergency Support

The Emergency Support service is activated on a user-demand basis, and the related BSM products are delivered to the end-users within a few days after the suppression of the fire event. Depending on the input satellite data, the service provides BSMs at high spatial resolution (20-30 meter pixel size, and minimum detected fire size of 1 hectare), and very high spatial resolution (2-8 meter pixel size, spatial accuracy of 4-10 meters, detected fire size of 0.5 hectares), as well as damage assessments at a prefecture level with respect to the existing Corine LC database.

Figure 4 depicts cases of BSMs and damage assessments derived for selected wildfires in Greece from 2007-2011, and an example of a final map generated after an Emergency Support activation originated from the SAFER project for the island of Corsica. The same methodology can be applied for Emergency Response applications, allowing the deployment of rapid mapping services.

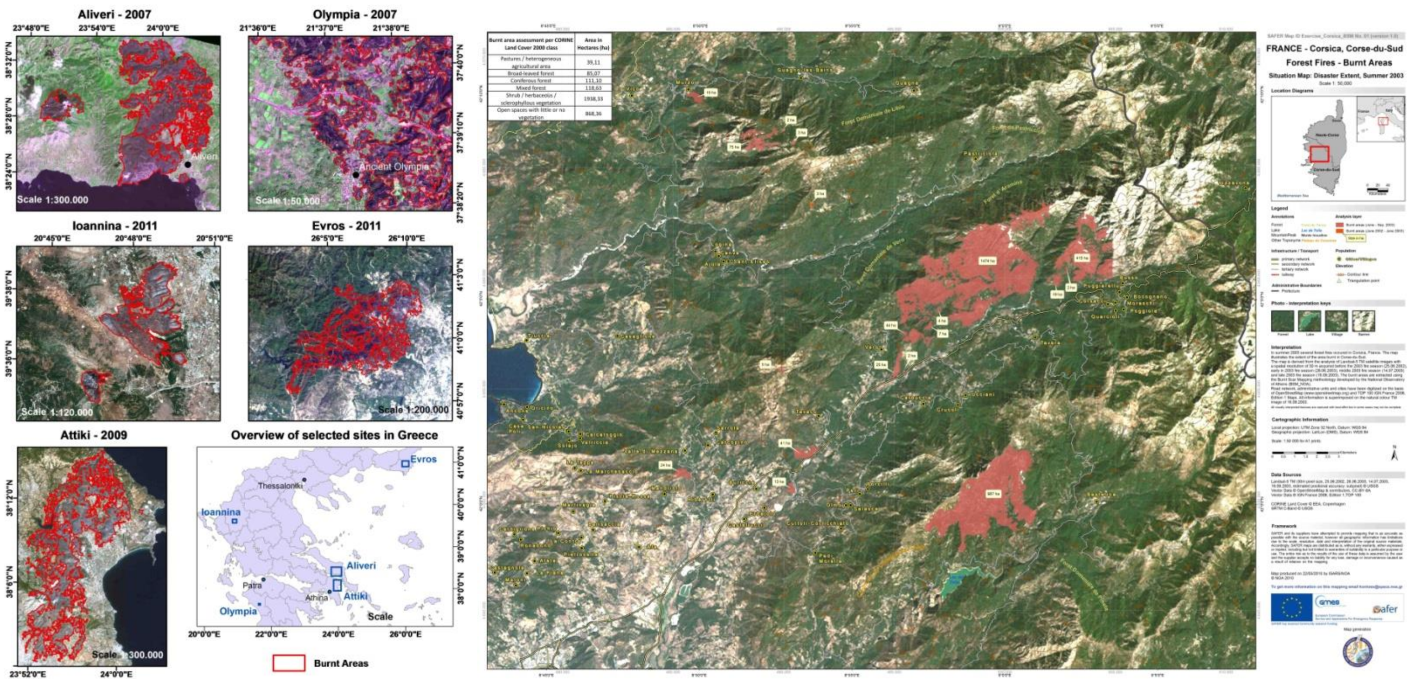

Figure 4. (left) BSM mapping and damage assessment for selected fire events in the period 2007-2011 over Greece, and (right) Map product following the Emergency Support activation in Corsica. Image Credit: NOA

The entire BSM service chain was extensively evaluated in the framework of the GMES project SAFER, by subjecting it through a thorough standardization procedure using several criteria (thematic accuracy, user support, sustainability of the means used, transferability, timeliness, etc). Following a test scenario for the island of Corsica, the NOA BSM service was qualified – top of its class - as an end-to-end service for fire related Emergency Support activities for integration to operational scenarios all over Europe.

3.2 Diachronic damage analysis

The established fully automatic processing chain has been successfully applied to the entire archive of Landsat imagery acquired over Greece, spanning from 1984-2012, which has been collected and managed at NOA. The number of full Landsat TM and ETM+ frames in the framework of the study was 415. These BSM products were generated for the first time to such a temporal and spatial extent, and are ideal to use in further environmental time series analyses, production of statistical indexes (frequency of fire occurrence, geographical distribution and number of fires over the Greek territory) and applications, including change detection and climate change models, urban planning, and correlation with manmade activities. Diachronic mapping is provided through an innovative Web-GIS application, allowing the user community to preview the annual BSM records (Figure 5a) at a fully detailed scale, as well as to interact with relative Heat-map and LC products (Figure 5b,c,d).

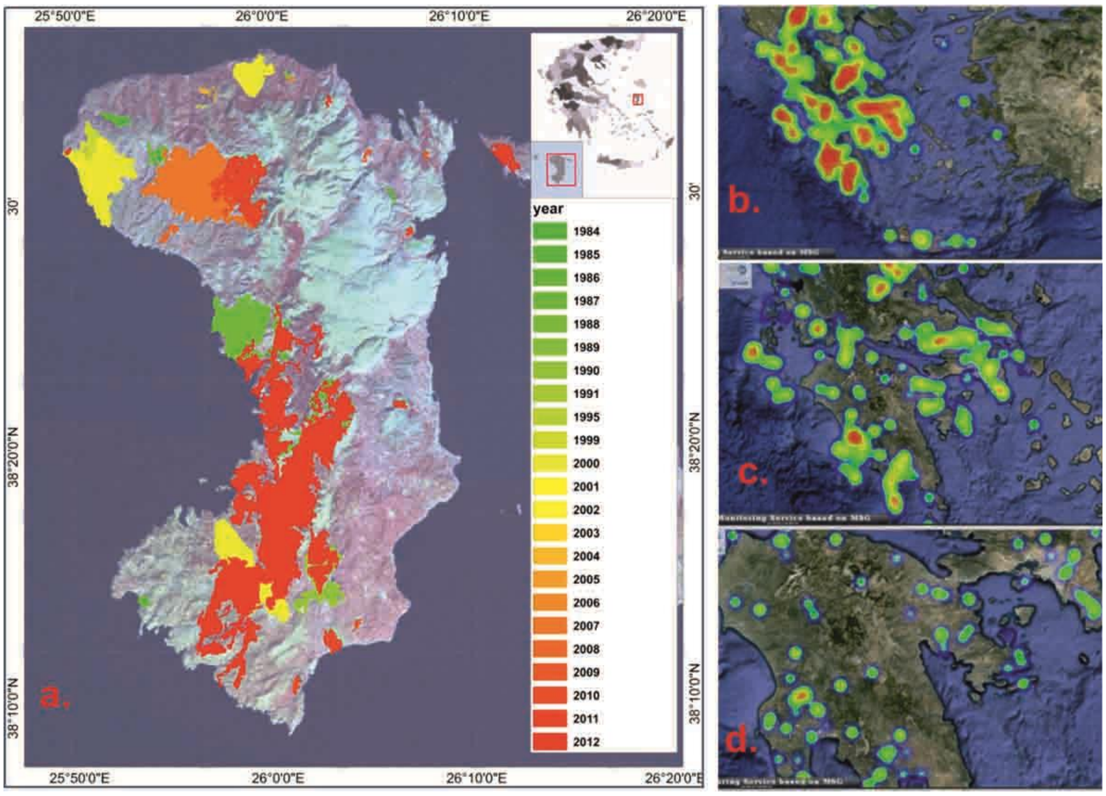

Figure 5. a.) Diachronic BSM and damage assessments over the Chios island from 1984 to 2012), b., c., d.) Heat map depicting the concentration of burnt areas, at different zoom levels over Greece. Image Credit: NOA

4. Conclusions

This paper highlights the operational capacities of NOA in delivering high quality thematic products to the end-user community for fire monitoring, BSM and damage assessment during and after a wildfire crisis. The capacities established and qualified in the framework of the GMES RISK-EOS and SAFER projects are enhanced through the TELEIOS project with the use of semantic and database technologies and will be further expanded in the newly European Commission-funded project BEYOND, aimed at **Building a Centre of Excellence for Earth Observation based monitoring of Natural Disasters in south-eastern Europe**.

We briefly presented the operational services for near real-time fire monitoring and burnt area delineation, for rapid mapping and/or diachronic mapping, which are being supported by NOA. These services meet the criteria for cost efficiency, thematic accuracy, timeliness, and large geographic coverage extent. In general, the EO-based approaches are by far exceeding the mapping standards established by foresters at any administrative level (region/country/continent) for supporting actions relating to wildfire recovery management and fire emergency support and response. The offered services are characterized by high flexibility and transferability to any geographic area. On this basis, the use of satellite data in dedicated processing chains form suitable and robust solutions for operational fire detection and damage assessments at European and national levels. Moreover, these services may be used for fire risk planning, by combining diachronic burnt area patterns with LC and geomorphology maps, thus identifying the most vulnerable areas that need continuous supervision and immediate intervention for the protection of environmental and social sustainability.

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