Consiglio Nazionale
delle **Ricerche**

13th EARSeL Workshop on Forest Fires 2024

REMOTE SENSING OF FOREST FIRES: LESSONS LEARNED AND FUTURE CHALLENGES UNDER A CHANGING CLIMATE

Milan, 19th-20th September 2024

editors
Daniela Stroppiana
Gloria Bordogna
Luigi Boschetti
Pietro Alessandro Brivio
Paola Carrara

BOOK OF ABSTRACTS

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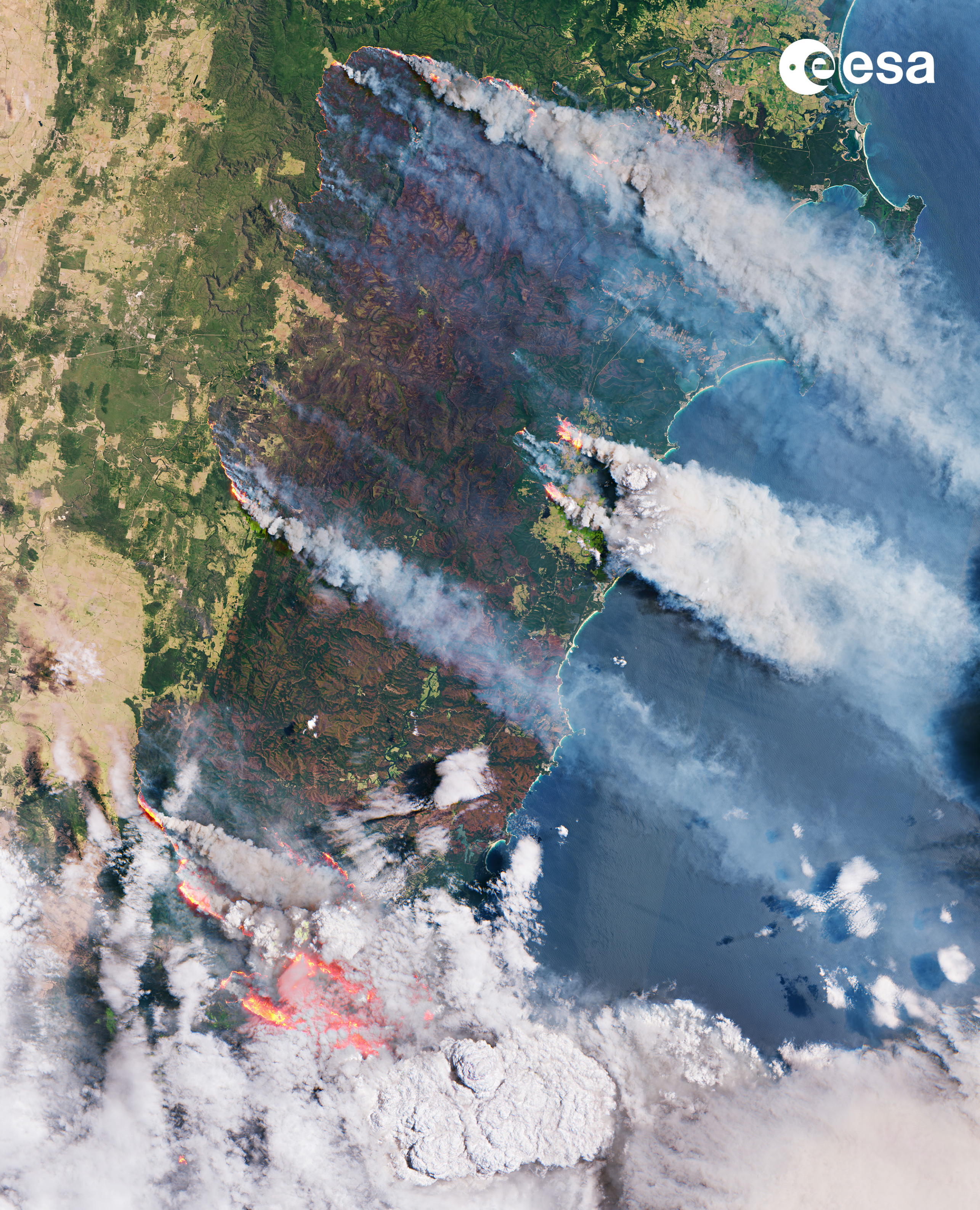

Smoke and flames in Australia

Ferocious bushfires have been sweeping across Australia since September, fuelled by record-breaking temperatures, drought and wind. The country has always experienced fires, but this season has been horrific. A staggering 10 million hectares of land have been burned, at least 24 people have been killed and it has been reported that almost half a billion animals have perished.

The Copernicus Sentinel-2 mission has been used to image the fires. The Sentinel-2 satellites each carry just one instrument – a high-resolution multispectral imager with 13 spectral bands. The smoke, flames and burn scars can be seen clearly in the image shown here, which was captured on 31 December 2019. The large brownish areas depict burned vegetation and provide an idea of the size of the area affected by the fires here – the brown ‘strip’ running through the image has a width of approximately 50 km and stretches for at least 100 km along the Australian east coast.

Read more: Australia: like a furnace

CREDITS

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LICENCE

Observing the Earth

Sentinel-2

Copernicus

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The European Space Agency (ESA) is Europe's gateway to space. Its mission is to shape the development of Europe's space capability and ensure that investment in space continues to deliver benefits to the citizens of Europe and the world.

ESA is an international organisation with 22 Member States. By coordinating the financial and intellectual resources of its members, it can undertake programmes and activities far beyond the scope of any single European country.

The Agency is present in seven sites, located in different parts of Europe.

ESA – ESRIN center, based in Frascati, near Rome, Italy, is the ESA centre for Earth Observation.

ESA and Earth observation

ESA is a world-leader in Earth observation and remains dedicated to developing cutting-edge spaceborne technology to further understand the planet, improve daily lives, support effective policy-making for a more sustainable future, and benefit businesses and the economy.

We develop three kinds of missions:

1. The **Earth Explorer missions** are designed to improve our understanding of Earth. They use cutting-edge space technologies to learn more about the interactions between the atmosphere, biosphere, hydrosphere, cryosphere and Earth's interior, essential how Earth works as a system. Importantly, they address scientific questions that help predict the effects of climate change and address scientific questions that have a direct bearing on societal issues that humankind is likely face in the coming decades. While these missions are fulfilling their original brief, they are all surpassing expectations with their data finding a multitude of uses in real-world applications to improve everyday life.
2. The **Sentinel missions** are developed specifically for the European Union's Copernicus programme – the largest environmental monitoring programme in the world. By

providing a set of key information services for a wide range of practical applications, the programme is making a step change in the way we manage the environment, understand and tackle the effects of climate change, and safeguard everyday lives. Each Sentinel mission carries state-of-the-art technology to deliver a stream of complementary imagery and data tailored to the needs of Copernicus. These data are free of charge and open to users worldwide, which not only eases the essential task of monitoring the environment, but also helps stimulate enterprise, creating new jobs and business opportunities.

3. The economic and social benefits of accurate weather forecasts are huge; they allow us to make informed decisions, whether it be harvesting a crop before it rains, gritting the roads to prevent accidents, routing aircraft and marine traffic to avoid adverse conditions or simply plan everyday activities. Thanks to the cooperation between ESA and Eumetsat, Europe has a fleet of **meteorological satellites**, in both geostationary and polar orbits, to provide essential information for weather forecasts. Information from these satellites is also used to understand climate change.

ESA has also been instrumental in setting up a number of initiatives such as the **Climate Change Initiative**, the **Earth Observation Science for Society** activities and the **International Charter 'Space and Major Disasters'**.

Finally, with satellites delivering a mind-boggling amount of data about our planet, along with the availability of the latest digital technologies, there are countless opportunities for innovation and commercialisation. Building on the concept of New Space, ESA is using its position as a lead innovator to support and expand the European commercial Earth observation sector.

To know more, visit our website www.esa.int or follow us on X and Instagram

Workshop Program
13th EARSeL

Workshop on Forest Fires 2024

Thursday, 19th September 2024

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Preface

On September 19-20, 2024, the 13th EARSeL Workshop on Forest Fires, entitled "Remote Sensing of Forest Fires: Lessons learned and future challenges under a changing climate", took place in Milan, Area Territoriale di Ricerca di Milano 1 (AdRMi1), Consiglio Nazionale delle Ricerche (CNR). The workshop gathered national and international scientists, all deeply involved in the use of Remote Sensing to monitor forest fires and to assess their impacts on the biosphere. We are all aware that fires have relevant short-term and long-term impacts on human communities and the ecosystems, having at the same time an essential role in maintaining ecological balance. Wildfires are a dominant disturbance, and research has well proved their inter-relationship with climate change. In fact, warmer and drier conditions increase fire risk and fire severity in most of the world ecosystems and the extreme fire events occurred in the recent years have been observed and investigated also thanks to remote sensing techniques able to provide a global and frequent picture of fire occurrence.

Over the course of two days, the workshop focused on the use of Earth Observation data to monitor forest fires throughout their various stages, including risk assessment, prediction, real-time monitoring, impact analysis, and emission tracking. The interdisciplinary nature of this workshop aimed to foster a comprehensive exchange of knowledge, helping to consolidate past lessons, while identifying future challenges in the use of remote sensing technologies to manage and mitigate the effects of wildfires in a rapidly changing climate.

This collection of abstracts brings together the presentations and posters from the workshop, reflecting the broad use of remote sensing and presenting innovative tools, methodologies and products. We hope it will inspire new ideas, collaborations, and solutions in the wide field of application of remote sensing to wildfire monitoring.

We wish to express our sincere gratitude to all the participants, contributors, members of the scientific committee, organizers and sponsors who made this workshop possible, and we hope this workshop was an opportunity for increasing networking, strengthening existing and building new connections and collaborations among scientists involved in the remote sensing fire community.

For the organizing committee,

Daniela Stroppiana

Daniela Stroppiana

13th EARSeL Workshop on Forest Fires
19-20 September 2024, Milan, Italy

Keynotes

Toward Long-Term Global Fire Data Sets: Satellite-Based Fire Remote Sensing in the Age of the Beatles

Louis Giglio

Dep. Of Geographical Sciences, University of Maryland, USA

Corresponding Author: lgiglio@umd.edu

A long-term, multi-decadal, record of global burned area is needed to understand the interplay between human activity and climate change on fire occurrence and behavior.
At present, the longest consistent satellite-based record has been provided by the Moderate Resolution Imaging Spectroradiometer (MODIS) on-board NASA’s Terra and Aqua satellites.
A long-standing objective within the remote sensing community has been to compile a reliable long-term record of pre-MODIS global fire activity using data acquired with the older Advanced Very High Resolution Radiometer (AVHRR). Ongoing efforts toward achieving this goal have not yet been successful, and during the first portion of my presentation I will briefly survey the factors that confound its pursuit, noting some areas of progress. Next I will consider the question of when the satellite record of global fire activity actually begins.
The answer turns out to be the mid-1960s, more than decade before the AVHRR was first deployed.

The fire atlas of Portugal and its uses in research and management

José M.C. Pereira

Forest Research Centre, School of Agriculture University of Lisbon

In the mid-1990s, the Forest Research Centre started the development of a national-level, annual Fire Atlas, under contract with the Portuguese Forest Service. A single date of Landsat imagery was used to map fires, relying on supervised classification followed by thorough manual editing.

Since early in its development, the Fire Atlas started being used to support research and management in diverse domains. Fire management projects include national fire danger mapping and the delineation of a national fuelbreak network for the Portuguese Forest Service, rural-urban interface fire risk mapping for the Directorate-General for Territory, and fire regime mapping for the Agency for Integrated Rural Fire Management. Examples of research activities supported by the Atlas are fire frequency analysis, estimation of pyrogenic emissions, analysis of fire selectivity for diverse land cover types, characterization of the forest transition, spatially-explicit estimation of burned area trends, assessment of fuelbreak network performance, leverage assessment of prescribed and natural burns, and landscape-level fuel management planning.

Over the last couple of years, we have introduced two major improvements in the Atlas: i) improved temporal resolution, with monthly dating of the fire scars, and ii) development of an entirely new Atlas, using all Landsat images over Portugal available in Google Earth Engine and a convolutional neural network image classifier, leading to an improved product.

Talks

Global and Regional Burned Area Products of the ESA FireCCI Project: Current Products and Perspectives

M. Lucrecia Pettinari[1,*], Amin Khairoun[1], Erika Solano[1], Thomas Storm[2], Martin Boettcher[2], Emilio Chuvieco[1]

1 Universidad de Alcalá, Environmental Remote Sensing Research Group, Spain
2 Brockmann Consult GmbH, Germany

**Corresponding author:* mlucrecia.pettinari@uah.es

Keywords: earth observation, burned area, global, regional, ESA CCI

Challenge

Earth Observation data is a widely used and very advantageous source of information for burned area (BA) detection, as it provides global information in a systematic way. Several polar-orbiting satellites provide information in spectral regions suitable for BA detection, particularly infrared data at different wavelengths: near (NIR), short-wave (SWIR) and thermal. Within the European Space Agency (ESA) Climate Change Initiative (CCI), the FireCCI project has the objective to develop and validate burned area algorithms to meet, as far as possible, GCOS (Global Climate Observing System) Essential Climate Variable (ECV) requirements for (consistent, stable, error-characterized) global satellite data products from multi-sensor data archives. Since the start of the CCI Programme, more than ten years ago, FireCCI has developed different BA products based on surface reflectance and active fire information from a variety of ESA and NASA sensors.

Product	Coverage	Input data (sensor)	Time Series	Spatial Resolution	Related publication (DOI)
FireCCI51	Global	SR: MODIS AF: MODIS	2001-2021	Pixel: 250 m Grid: 0.25°	10.1016/j.rse.2019.111493
FireCCIS311	Global	SR: SYN (OLCI+SLSTR) AF: VIIRS	2019-2022	Pixel: 300 m Grid: 0.25°	10.1016/j.rse.2022.113298
FireCCILT11	Global	SR: AVHRR LTDR	1982-2018	Pixel: 0.05° Grid: 0.25°	10.1016/j.jag.2021.102473
FireCCISFD11	Sub-Saharan Africa	SR: MSI AF: MODIS	2016	Pixel: 20 m Grid: 0.25°	10.1016/j.rse.2018.12.011
FireCCISFD20	Sub-Saharan Africa	SR: MSI AF: VIIRS	2019	Pixel: 20 m Grid: 0.05°	10.1016/j.scitotenv.2022.157139
FireCCISFDL	Large Areas in Amazonia, Siberia and Sahel.	SR: TM, ETM+, OLI	1990-2019	Pixel: 30 m	Not yet published.

Methodology

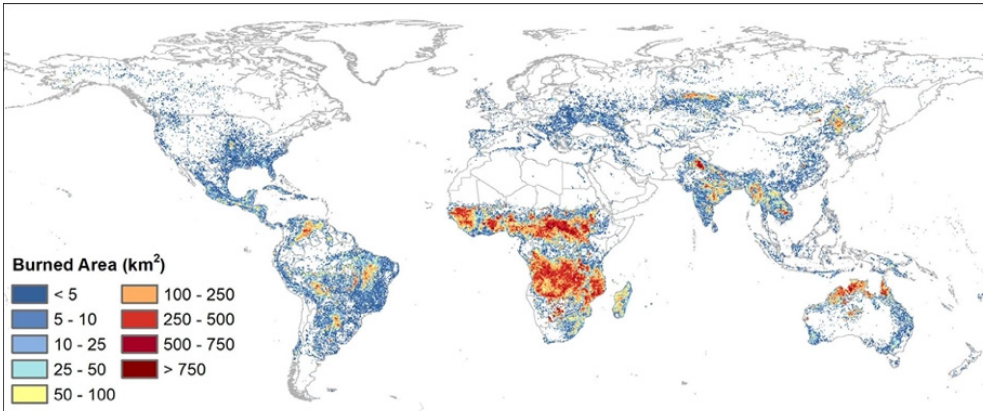
The current suite of products obtained from the FireCCI algorithms spans from 1982 to 2022, with plans to expand it further into the future. Through the life of the FireCCI project, the different algorithms for BA detection have been refined, based on validation results of previous versions and new sensors' data becoming available. The characteristics of the different products are detailed in the table below, showing the coverage, input data (being SR the surface reflectance and AF the active fire information), time series already produced, the resolution of the pixel and grid products, and the link to the related scientific publication where more information can be obtained about each product.

Expected results

The global BA products detect an average of 4.55 Mkm2 (FireCCI51), 4.78 Mkm2 (FireCCILT11) and 4.79 Mkm2 (FireCCIS311) in their respective time series, with peaks in 2011 and 2012 in FireCCI51 and FireCCILT11. In the three years of overlap between FireCCI51 and FireCCIS311, the latter detects a mean of 25.5% more BA than FireCCI51. Although the spatial resolution of FireCCIS311 is a bit lower than FireCCI51 (300 m vs. 250 m), an improved algorithm, the availability of SWIR information in the SYN bands of Sentinel-3 and the use of VIIRS active fires improved the results of this product. These results are also confirmed by the validation of the products. Regarding the medium resolution products, also called Small Fire Dataset (SFD), FireCCISFD11, using only input SF from Sentinel-2 A and MODIS hotspots, detected 4.92 Mkm2 in Sub-Saharan Africa, 58% more than the BA detected in that area by FireCCI51, and even more than it was detected for 2016 globally (4.15 Mkm2). In the case of FireCCISFD20, it takes advantage of the additional data provided by Sentinel-2B, duplicating the input data amount and temporal resolution. Another improvement is the use of VIIRS AF, with a higher spatial resolution. This allowed to detect 4.84 Mkm2 burned in Sub-Saharan Africa in 2019, which represents 83% more BA than the one detected by FireCCI51 and 58% more than FireCCIS311. An additional exercise to detect BA using medium resolution sensors is underway using Landsat images to detect BA for the period 1990-2019 in three large areas (more than 1Mkm2 each) in Amazonia, Siberia and Sahel.

Outlook for the future

With the foreseen end of the MODIS programme and the decrease in quality of its observations in the upcoming years, the Sentinel-3 satellites provide good information to continue the global BA detection at a similar spatial resolution, as shown by the FireCCIS311 BA product. This product is expected to be produced for further years into the future. Complementary, we plan to study options to homogenize FireCCI51 and FireCCIS311 results, to obtain a consistent product starting in 2001 and extending into the future. What is more, the availability of medium resolution sensors such as Sentinel-2 and Landsat provide the opportunity to develop BA products at higher spatial resolution, which allows to detect many small fires not detected by coarse resolution sensors. But this also poses the challenge to download, process and archive massive amounts of data, with its associated costs in time and resources. The FireCCI project is currently developing a global algorithm for BA detection using Sentinel-2, based on the FireCCISFD20. When this product becomes available, it is expected that it will substantially increase the BA detected globally, and improve the knowledge of the scientific community about the real extent of the fire phenomenon.



Total burned area for the year 2022 obtained from the FireCCIS311 grid product.

Burned Area Mapping with Sentinel-2 Based on Reflectance Modelling and Deep Learning – Global Calibration and Preliminary Validation

Marc Padilla[1,*], Ruben Ramo[1], Sergio Sierra[1,2], Bernardo Mota[3], Roselyne Lacaze[4], Kevin Tansey[5]

1 Complutig, Spain
2 Universidad De Cantabria, Spain
3 National Physical Laboratory, UK
4 Hygeos, France
5 University of Leicester, UK

**Corresponding author:* marc.padilla@complutig.com

Keywords: fire disturbance, terrestrial globe, sentinel-2, VIIRS, calibration

Challenge

Currently, global burned area products are only available at hectometric spatial resolutions (300-500 m) that can include large errors, which propagate to down-stream processes, such as fire emissions and the role within the global carbon cycle. A global decametric resolution (20-30 m) burned area product would greatly minimize pixel scale errors and improve the related fire estimates. Improvements in computing capacities and easier access to decametric spatial resolution reflectance data are facilitating the generation of 20 m products for large regions. The current study presents a novel calibration approach for a sensor independent burned area algorithm, including a validation at global scale. This algorithm is based on a reflectance model of fire effects and was originally implemented to use Sentinel-3 data in the framework of the Copernicus Global Land Service (CGLS). We present (1) the calibration of the main algorithm parameters and (2) a cross-validation analysis based on a global stratified random sample of reference data.

Methodology

The proposed mapping method is based on a deep learning model that designed to process time series of Sentinel-2 reflectance data. The goal is to predict the probability that the burned pixel fraction is above 0.2 ($prob(f_b>0.2)$), as a measure that takes into account both the magnitude and the uncertainty of the predicted fraction. This latter is then combined with a spatio-temporal probability mask, based on active fire detections densities (AFdensity) from the VIIRS active fires product. A convolutional neural network

(CNN) is trained with real and simulated data, using a combination of surface reflectance semi-empirical models, that take into account (1) the fire impacts over vegetation and subsequent surface reflectance changes, and (2) the associated surface reflectance anisotropy. The semi-empirical models are calibrated with time series of reflectance observations at active fires detections. The combined probability, between the CNN burned area prediction and the density of active fires, is based a binomial regression calibrated with reference data. The reference dataset used here was generated at 106 Landsat scenes for year 2019 (https://doi.org/10.21950/BBQQU7), in the framework of the Copernicus Climate Change Service. A preliminary evaluation of the quality of the calibration was based on a common leave-one-out cross-validation analysis. The reference dataset was compared with the algorithm outputs on each Landsat scene, by excluding that scene on the calibration of the binomial model.

Expected results

The joined distribution of *prob*(f_b>0.2) and AFdensity at the reference burned classifications is distinct from that at the unburned classifications (Figure 1). While burned classifications tend to have large values of *prob*(f_b>0.2) and AFdensity, unburned classifications tend to have very low values of *prob*(f_b>0.2) and intermediate to low values of AFdensity. The proportions of burned classifications (right panel of Figure 1) shows a clear pattern with a rather smooth border between two regions, one with large values (up to one) and another with low values (as low as zero). However, some ‘outliers’ are observed as isolated bins high proportions of burned classifications at intermediate to high values of prob(f_b>0.2) and low values of AFdensity. The binomial model calibration with this dataset is able to derive robust predictions of probability of burned classification with an overall similar pattern than the proportion of burned classifications, without being affected by the outliers (Figure 2). The probability threshold that maximizes accuracy of the classification is 0.3, and therefore it is used by the algorithm to label the estimates as ‘burned’ or ‘unburned’. The leave-one-out cross validation shows high global accuracies, with a Dice of coefficient (DC) of 81.7%, a commission error ratio (Ce) of 12.6%, an omission error ratio (Oe) of 23.2% and a relative Bias (relB) of -12.0%. Figure 3 shows, for illustrative purposes, the comparison between algorithm output burned area maps and reference for a Landsat scene with one of the highest accuracies.

Outlook for the future

The capacity of the binomial model to capture the observed data suggests that it is a good candidate for combining reflectance-based burned area predictions and spatio-temporal densitiy probabilities of active fire detections. The observed 'outliers' (isolated bins with high proportions of burned classifications with intermediate values of *prob*(f_b>0.2) and low values of AFdensity) are compatible with land surface changes similar to burns but that are not related to fire effects. The robustness of the binomial model against those 'outliers' and its capacity to capture the overall data patterns reflects its potential to screen out land surface changes similar to burns but not related to fire. The high accuracies observed at the leave-one-out cross-validation analysis (DC 81.7%) reflect the usefulness of the mapping methods and calibration approaches presented here, which could pave the way to an important step forward in improving the accuracy of global burned area maps.

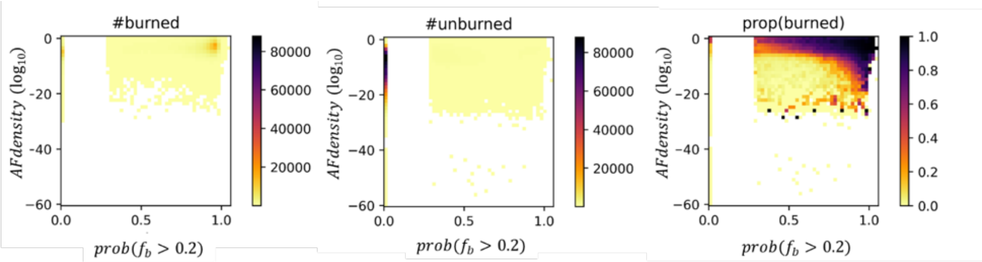


Figure 1. 2-dimensional histograms showing the joint distributions of *prob*(f_b>0.2) and AFdensity for the observations classified as burned by the reference data (left panel), as unburned (middle). The proportion of burned classifications, prop(burned), at the same histogram bins is shown on the right panel.

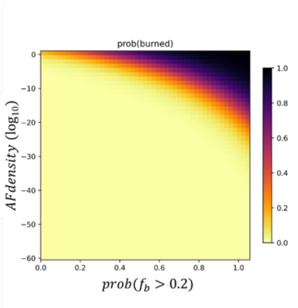


Figure 2. Probability that a reflectance observation is classified as burned by a reference dataset estimated by the binomial model at the same variable dimensions as in Figure 1.

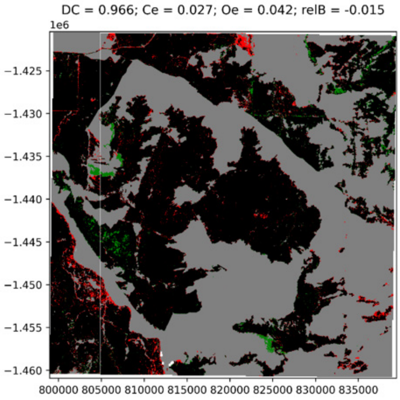


Figure 3. Comparison map between the algorithm output and the reference data at sampling unit TSA 097072, located in Northern Australian Tropical savanna, from 15th May 2019 to 23rd November 2019. True burned area is represented in black, true unburned in grey, omission and commission errors in red and green respectively. DC = 0.966; Ce = 0.027; Oe = 0.042; relB = -0.015.

Complementary Earth Observation Approaches to Advance Fire Emission Estimation

Matthias Forkel[1,*], Daniel Kinalczyk[1], Christine Wessollek[1], Niels Andela[2], Jos de Laat[3], Vincent Huijnen[3], Christopher Marrs[1], Dave van Wees[2], Stephen Plummer[4]

1 TUD Dresden University of Technology, Faculty of Environmental Sciences, Dresden, Germany
2 BeZero Carbon Ltd., London, UK
3 Royal Netherlands Meteorological Institute (KNMI), De Bilt, The Netherlands
4 European Space Agency, ESRIN, Frascati, Italy

**Corresponding author:* matthias.forkel@tu.dresden.de

Keywords: wildfire, sentinels, emission factors, Amazon, surface fuels

Challenge

Fire emissions depend on fuel amount and type, moisture conditions and burning behavior. However, the effects of fuels on the combustion process and on the composition of fire emissions are simplified in current Earth observation based fire emission inventories. Bottom-up fire emission inventories use satellite data of burned area or fire radiative power, estimate fuel consumption and apply biome-dependent emission factors to estimate fire emissions. However, they are poorly constrained with respect to total fire emissions. As an alternative, top-down approaches using atmospheric satellite instruments provide an integrated view on fire emissions but cannot resolve how fuel properties contribute to those emissions. Here we aim to estimate fire emissions from three complementary approaches to provide insights into burning behavior and emissions.

Methodology

We developed three approaches to quantify fire emissions, including top-down and bottom-up approaches based on various satellite observations. KNMI.S5p uses Sentinel-5p data to estimate CO and NOx emissions, employing a top-down approach with the IFS atmospheric model and a mass budget method. GFA.S4F utilizes active fire data from VIIRS to estimate burned area and combines it with fuel consumption and emissions factors for each fire type. TUD.S4F integrates multiple satellite observations in a data-model fusion approach to estimate fire emissions. TUD.S4F estimates fuel dynamics and combustion, by computing biomass compartments, turnover, fuel components, fuel moisture, combustion completeness, fuel consumption, and emissions. It uses LAI (Sentinel-3), land cover (ESA CCI), soil water index (ASCAT), and burned area datasets and applies a chemical-based model to compute dynamic emission factors. Calibration ensures consistency with datasets like canopy height (GEDI), biomass (ESA CCI), live fuel moisture content, and vegetation optical depth (VODCA and SMOS). TUD.S4F operates at 333x333 m spatial resolution and 10-day temporal resolution.

While we already conducted a detailed comparison of the estimated fire emissions for the Amazon and Cerrado and with further fire emission inventories such as GFED, comparison for other regions (Europe, Southern Africa, and Siberia) are currently conducted.

Expected results

Estimates for Amazon and Cerrado fire emissions in 2020 reveal significant carbon release. The three approaches KNMI.S5p, GFA.S4F and TUD.S4F show comparable total fire emission estimates (Figure 1). Discrepancies with alternative fire emission approaches stem from differences in burned area input data and the used approach. Forest and deforestation fires contribute significantly to emissions, highlighting the importance of analysing their combustion dynamics further. CO emissions vary among fire types and events. Woody debris dominates fuel consumption and emissions across all fire types, especially in forest and deforestation fires. However, discrepancies in fuel load estimates between TUD.S4F, GFED and ancillary datasets highlight the challenge of accurately quantifying fuel loads and their impact on fire emissions.

Despite uncertainties in estimated surface fuels, TUD.S4F's representation of chemical relationships enables investigation of estimated emission factors. We find a gradient in the emission factor of CO from savannas to topical forests, suggesting more complete combustion in savanna fires (flaming) and incomplete combustion in forest fires (smouldering). Preliminary results for the other regions show larger divergence of the three fire emission approaches but comparable effects of woody debris on total fuel consumption and emission factors.

Outlook for the future

Looking ahead, addressing the discrepancies in fire emission estimates for forests and deforestation areas, particularly in global fire models, is imperative for accurately predicting future fire behavior and emissions. Enhanced quantification of fuel components, composition, and consumption is essential, underscoring the importance of direct field observations and improved satellite-based methods for estimating surface fuels. Additionally, understanding the implications of woody debris burning on air quality and carbon turnover in Amazon rainforests is critical for mitigating its adverse effects on ecosystems and human health. Collaborative research efforts and innovative remote sensing approaches will be key to refining fire emission estimation methodologies and better managing wildfires in the face of changing climate and land use patterns. We aim to present near-real time results for 2024 at the workshop.

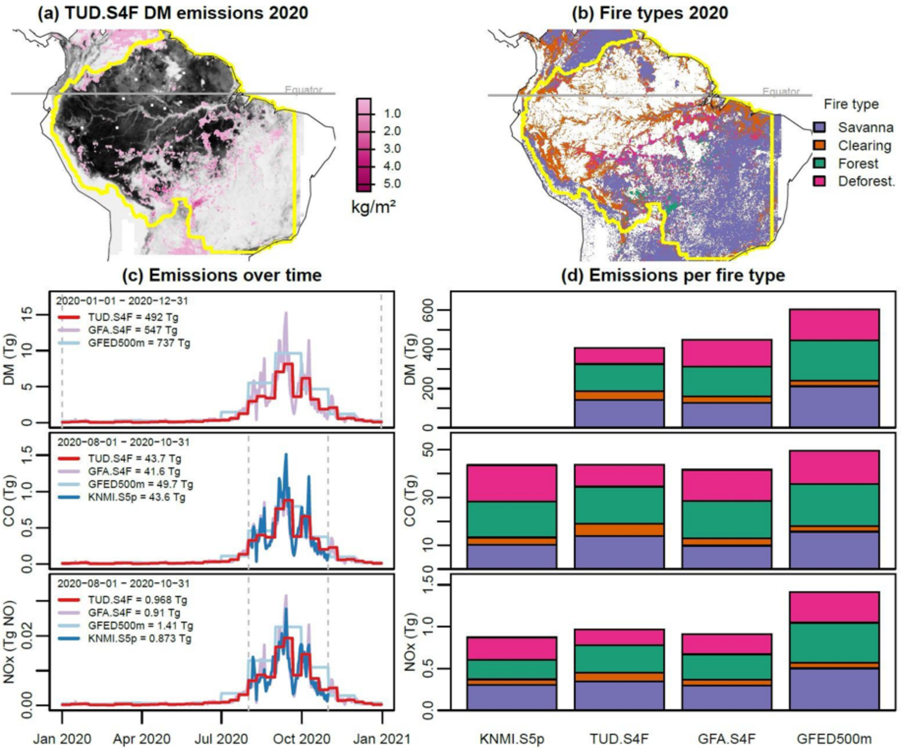


Figure 1. Fire emissions in the Amazon and Cerrado in 2020. (a) Total dry matter emission from TUD.S4F; (b) Fire types; (c) Time series of dry matter, CO and NOx emissions from complementary approaches; (d) Emissions stratified by fire type.

A Deep Learning Approach for Active Fire Detection Using Multi-Temporal Geostationary Satellite Data

Jayendra Chorapalli[1,2,*], Max Bereczky[1], Dmitry Rashkovetsky[1], Paul Walther[2], Martin Werner[2]

1 OroraTech GmbH, Germany
2 Technical University of Munich, Department of Aerospace and Geodesy, Germany

**Corresponding author:* jayendra.chorapalli@ororatech.com

Keywords: wildfire detection, earth observation, geostationary satellite data, Himawari-8/9, convolutional neural network

Challenge

Wildfires, both a natural phenomenon and a destructive force, significantly affect the environment, ecosystems, economies, and public security. Detection and real-time monitoring of wildfire locations are crucial in fighting wildfires and reducing human casualties and property damage. Geostationary satellites, such as Himawari-8/9, offer unique advantages due to their high-frequency data acquisition, enabling the characterization of rapidly changing fire dynamics. However, traditional rule-based remote sensing methods used for fire detection in geostationary satellites are not sensitive enough to detect small fires, e.g., due to coarse sensor resolution. Furthermore, the rigidity of these approaches hinders their adaptability to diverse climate zones and regional differences. Applying deep learning-based methods is difficult as the skewed distribution of fire versus non-fire areas in the captured data and the temporal disjunct of labels and satellite images pose significant problems.

Methodology

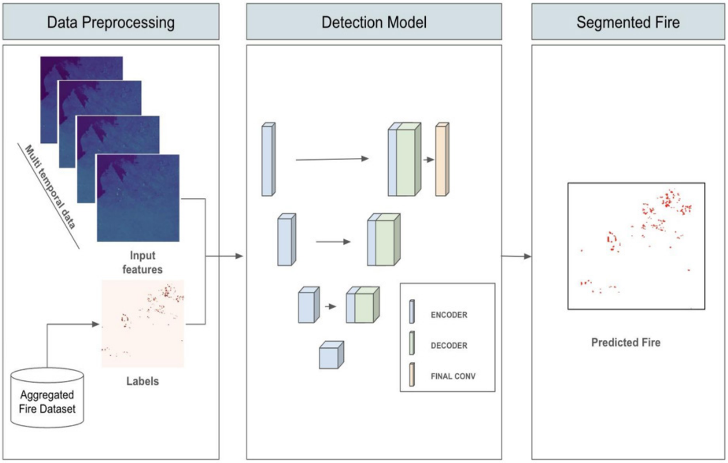
To address these challenges, we propose a deep learning approach for detecting active fires trained on multitemporal geostationary satellite data. As labels, we utilize high-resolution multi-sensor active fire detections. They are generated by aggregating individual detections from various sensors with lower ground sampling distances (GSD) than the Himawari-8/9 satellites, hypothesizing that these high-resolution labels can also improve the detection capabilities of smaller fires in coarse-resolution imagery. To further improve the model's capacity for detecting fires in their onset, samples are not looked at independently but in batches containing images acquired at 4 consecutive timestamps, evenly spaced 30 minutes before the corresponding label timestamp. Subtle changes in the signal strength caused by the start of a fire can be detected more effectively. In addition to the information contained in the input bands, auxiliary data such as land cover, biome types, elevation information, and temporal information (i.e., time of day, day of year) are evaluated as potential features in the training process. Data from 2020-2021 is used for training and 2022 for testing. To consider the data's multi-modal and time-dependent properties, we propose using a time-aware convolutional neural network (3D U-Net) to perform a pixel-based segmentation on the input images. The model's performance is evaluated using the Jaccard Index, Precision, Recall, and F1 score.

Expected results

By leveraging a diverse array of data sources, including multi-temporal satellite imagery, land cover, biome types, and temporal insights, we expect the model to exhibit an improved capacity for detecting smaller fires that are typically challenging to detect using rule-based methods. We expect that including observations from earlier stages of the fire contributes to the ability of the model to detect fires earlier than existing rule-based approaches. The effectiveness of our approach is rigorously evaluated against established benchmark fire products, providing a comprehensive measure of its performance in real-world scenarios. Additionally, a comparative analysis using national bushfire data provided by Geoscience Australia ascertains our model's performance and reliability in wildfire detection. Furthermore, our work reveals the critical input features influencing the model's performance. Identifying these key features will not only enhance our understanding of the factors that significantly impact wildfire detection but also guide the optimization of the model for improved detection performance. The key features are also checked with domain experts to ensure the right parameter selection.

Outlook for the future

To test the transferability of the model to other sensors and regions, we will test its performance when applied to data from the ABI sensor onboard GOES satellites by using transfer learning. While ABI sensors share almost similar wavelengths to the AHI sensors on the Himawari satellites, they operate in different regions on Earth. This provides a platform to test our model's generalizability in detecting fires. Additionally, we will explore the model's performance when applied to the SEVIRI sensor onboard satellites from the Meteosat series. Furthermore, we will test how different length time series affect the model's performance. Our exploration will extend to sequential deep learning models such as Long Short-Term Memory (LSTM) and Gated Recurrent Units (GRU). These advanced techniques promise to significantly enhance our understanding and prediction of wildfire progression by improving the capture of temporal relationships within the data.



Workflow of the proposed solution.

Multi-resolution Monitoring of the 2023 Maui Wildfires, Implications and Recommendations for a Dedicated Fire Monitoring Satellite Constellation

David P. Roy[1,2,*], Hugo De Lemos[1], Haiyan Huang[1], Louis Giglio[3], Rasmus Houborg[4], Tomoaki Miura[5]

1 Center for Global Change and Earth Observations & Department of Geography, Michigan State University, USA
2 Center for Global Change and Earth Observations, Michigan State University, USA
3 Department of Geographical Sciences, University of Maryland, USA
4 Planet Labs PBC, San Francisco, USA
5 Department of Natural Resources and Environmental Management, College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa, USA

**Corresponding author:* roydavi1@msu.edu

Keywords: Hawaii wildfire disaster, MODIS, VIIRS, PlanetScope, future needs

Challenge

The August 2023 wildfires over the island of Maui, Hawaii were one of the deadliest U.S. wildfire incidents on record with 100 deaths and an estimated U.S. $5.5 billion cost. This presentation documents the incidence, extent, and characteristics of the 2023 Maui wildfires using multi-resolution global satellite fire products, and in so doing demonstrates their utility and limitations for detailed fire monitoring, and highlights outstanding satellite fire observation needs.

Methodology

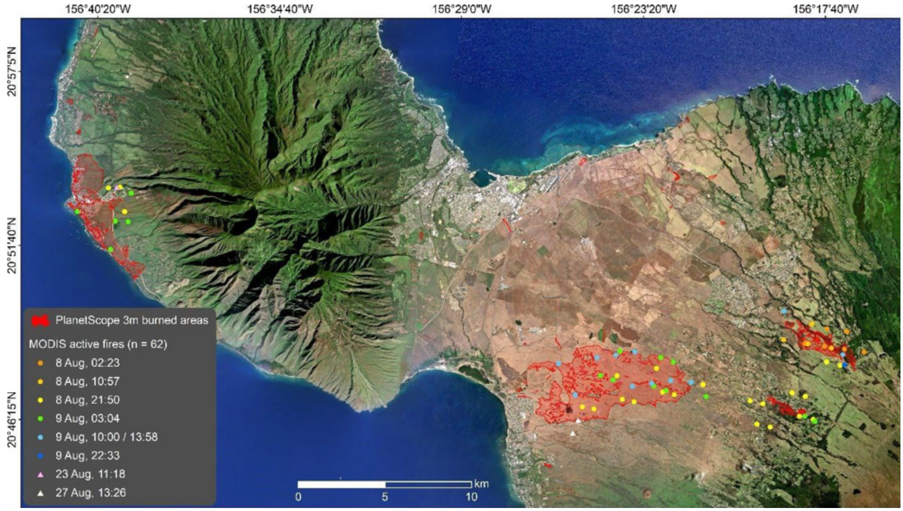
We present PlanetScope 3 m burned areas mapped across Maui using a published deep learning algorithm and compare the mapped results with the NASA 500 m Moderate Resolution Imaging Spectroradiometer (MODIS) burned area product. In addition, all the August 2023 active fire detections provided by MODIS on the Terra and Aqua satellites and by the Visible Infrared Imaging Radiometer Suite (VIIRS) on the S-NPP and NOAA-20 satellites are used to investigate the geographic and temporal occurrence of the fires and their incidence relative to the 3 m mapped burned areas. The geographic and diurnal variation of the fire radiative power (FRP), available with the active fire detections, is presented to show how energetically the fires were burning. The analysis is undertaken for all of Maui and for the town of Lahaina that was the major population center that burned.

Expected results

The utility of the different data sets for fire monitoring at local scale, and the needs for future fire monitoring of wildfire events such as those experienced over Maui, are discussed.

Outlook for the future

Given the importance and ongoing need for global wildfire monitoring as climate warming and drier conditions led to the potential for longer and more active fire seasons, a dedicated fire satellite constellation should be considered a priority. The presentation concludes with recommendations for a dedicated fire monitoring satellite constellation.



The August 2023 wildfires over the island of Maui, Hawaii were one of the deadliest U.S. wildfire incidents on record. Figure shows PlanetScope mapped 3 m burned areas (red vectors) and NASA MODIS Terra and Aqua 1 km active fire detections (circles, coloured by the day and time of detection) superimposed on a 3 m PlanetScope basemap image. The coastal town of Lahaina evident on the western slope of Mauna Kahālāwai was the major population centre that burned, and 17 other burned areas were detected across the isthmus separating western and eastern Maui, and on the western slopes of Mt. Haleakalā.

Regional Wildland Fuel Type Mapping Using Sentinel-2 Timeseries and Spectral-Spatial Support Vector Machines

Michail Sismanis[1,*], Dimitris Stavrakoudis[1], Nikos Georgopoulos[1], Konstantinos Antoniadis[1], Ioannis Z. Gitas[1]

1 Aristotle University of Thessaloniki, School of Forestry and Natural Environment, Laboratory of Forest Management and Remote Sensing, Greece

**Corresponding author:* msismanis@for.auth.gr

Keywords: fuel type mapping, Sentinel-2 time series, spectral-spatial, supervised classification

Challenge

Catastrophic wildfires of considerable size and intensity have taken place in Mediterranean countries in the recent past, resulting in major ecosystem damage, extensive area degradation and loss of human lives. Climate change is one of the biggest challenges of our times, imposing the need for the establishment of a national integrated fire risk assessment programme to address the continually increasing pressures on natural ecosystems. Forest fuels are one of the main components required for the estimation of wildfire danger attributes, i.e. fire ignition probability and wildfire propagation modelling, and consequently can be beneficial for nation-wide wildfire management policies. In the current work, a novel approach is presented for the accurate and updatable regional mapping of the distribution of wildland fuels using a novel approach that relies on a timeseries of Sentinel-2 images, auxiliary geographic information layers and supervised classification algorithms.

Methodology

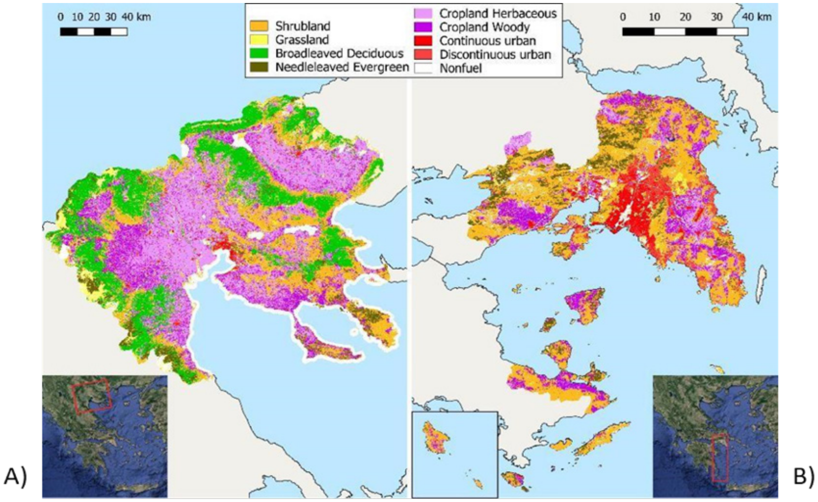
The work follows the FirEUrisk fuel type classification scheme, a newly established hierarchical scheme designed for both surface and crown fires in European landscapes. The proposed methodology partitions each study area into three distinct non-overlapping segments, considering that each segment contains a unique set of fuel types. The segments are categorized as urban, agricultural, and vegetation and a mapping methodology is designed for each one. All approaches employ a timeseries of six Sentinel-2 images and simultaneously utilize both spectral and spatial information, either in the context of fixed or adaptive pixel neighbourhoods. More specifically, for the mapping of agricultural and vegetation areas, the concept of supervised contextual spectral-spatial Support Vector Machine (SVM) classifiers with adaptive neighbourhoods is employed, while the differentiation of urban fuel classes makes use of a sliding window processing technique. The generated maps are then refined with the integration of other required auxiliary information from available thematic maps. The proposed methodology is tested in two study areas, namely Attica and Central Macedonia, both NUTS2 regions based on the official national administrative boundaries for the year 2022.

Expected results

Validation of the results was based on the Eurostat's Land Use/Cover frame Survey (LUCAS 2018) dataset and each sampling point was assigned to the target fuel classification scheme based on a set of quality criteria. To address the temporal distance from the collection of the dataset, all points were additionally photo-interpreted by experts to ensure that no major land cover changes occurred. All LUCAS points located in burned areas from the fire seasons of 2018-2022 were also discarded from the validation process. Precision, recall and F1-score metrics were used to assess the performance of the products. Perclass F1 score remains in most cases above 70%, indicating a good level of agreement with the target fuel classes without any persistent error. Overall accuracy ranged from 87% in Attica to 83% in Central Macedonia, constituting a promising score in both cases. Results demonstrate that the methodology proposed is a viable approach for the mapping of fuels in great detail, able to improve upon the already existing regional- or national level fuels maps available in Greece and provides an added layer of depth, in terms of mapping the fuels in different kinds of land cover.

Outlook for the future

Our work highlights an efficient fuel type mapping methodology, that can be potentially implemented on a national operational scale to generate fuel maps on a yearly basis, supporting national authorities in terms of forest fire management and decision making. However, the mapping of fuels through multispectral images can be a complex procedure when a high level of detail is required, given the high diversity and intermixing of vegetation, along with the absence of vertical or structural information. Future work could build upon the established approach and investigate the capacity to infer canopy height or understory composition, which were not examined in the context of this work, to further improve upon the existing established processes and generate updated and more detailed products.



Fuel type maps for (A) Central Makedonia and (B) Attica regions in Greece for 2022.

Analyzing Fuel Continuity by Using Terrestrial Laser Scanner Data to Simulate Fire Behaviour

Roberto Ferrara[1], Stefano Arrizza[1], Angelo Arca[1], Bachisio Arca[1], Pierpaolo Masia[1], Michele Salis[1], Andrea Ventura[1], Grazia Pellizzaro[1,*]

1 CNR, Istituto per la Bioeconomia (IBE), Sassari, Italy

**Corresponding author:* grazia.pellizzaro@ibe.cnr.it

Keywords: TLS, coniferous forests, vertical fuel continuity, forest fires, crown fire

Challenge

An accurate description of forest fuel is crucial for fire hazard mitigation planning by predicting potential fire behaviour. Landscape-level fuel maps provide the required inputs for the fire behaviour and growth models that are increasingly used to support fire management decision making. Both vertical and horizontal vegetation continuity are a key factor in fire propagation. However, many fuel characteristics are often operationally hard to be measured requiring manual and time-consuming field measurements. Several studies reported different potential applications of the terrestrial laser scanner (TLS) for forest stand and canopy variables estimation. TLS technology could be an effective alternative to overcome the limitations of the conventional ground-based forest inventory techniques. Objective of this study is to propose an automatic approach based on TLS technology to provide a detailed map of vegetation continuity within a forest ecosystem.

Methodology

The study was conducted in a Mediterranean coniferous forest in Sardinia The stand was characterized by complex terrain and a dense understory of different shrub species. TLS data were collected through multiple scans using a portable scanner (Leica BLK2GO). The point clouds generated by the instrument were co-registered and processed using a custom-developed R code. The code allowed for noise removal, filtering, separation of ground and woody components of trees and, finally, it classified vegetation into distinct vertical layers: canopy, understory, and forest floor. By subdividing the point cloud according to a regular grid (one meter by one meter), the spatial continuity between the layers was calculated. Based on the height of the shrub layer, the insertion height of the lowest branch and the fire line intensity of each cell, thermal continuity was determined to assess the probability of crown fire initiation from the lower layers.

Expected results

Based on results a fuel continuity map can be easily developed in order to better describe forest structure in areas characterized by both high and low vegetation continuity. Regions with dense canopy and continuous understory can be identified as susceptible to crown fire propagation, while areas with fragmented vegetation layers could potentially serve as natural barriers to fire spread. The integration of output of TLS data analysis into fuel model map can significantly improve prediction accuracy of fire behaviour simulators. Availability of high-resolution information of forest structure data, can more allow the fire behaviour simulators to effectively account for fine-scale variations in vegetation continuity, resulting in more reliable fire spread predictions.

Outlook for the future

The combination of detailed spatial data and advanced processing algorithms offers a powerful tool for fire management and risk reduction strategies. Future research directions include merging TLS data with other spatial datasets, such as aerial LiDAR and satellite imagery, to enrich the models and broaden their utility across various forest ecosystems and management scenarios. The proposed approach can lead to significant advancements in understanding and predicting fire behaviour, enabling better planning and more effective response to fire events.

Example of point cloud generated by TLS scans in the coniferous stand with different degree of vertical fuel continuity.

Assessing the Capabilities of GEDI to Predict Forest Canopy Bulk Density

Elena Aragoneses[1,*], Mariano García[1], Hao Tang[2], Emilio Chuvieco[1]

1 Univerasidad de Alcalà, Environmental Remote Sensing Research Group, Departamento de Geologia, Geografia y Medio Ambiente, Alcalà de Henares, Spain
2 Department of Geography, National University of Singapore, Singapore

**Corresponding author:* e.aragoneses@uah.es

Keywords: GEDI, canopy bulk density, fire risk, crown fire, FirEUrisk

Challenge

Wildfires are an important concern worldwide because they cause many damages, that is why they need to be better modelled. Crown fires, fires affecting tree crowns, are extreme wildfire events that deviate from average conditions causing catastrophic damage. This is the reason why having spatially explicit information of forest crown characteristics is essential to help fire risk modelling and prevention. One crown characteristic that is key to predict fire behaviour is canopy bulk density (CBD: the amount of canopy fuel per unit of canopy volume that is available for combustion in a fire). Using LiDAR, such as ALS and spaceborne LiDAR (ICESat/GLAS or GEDI), to retrieve the fuel vertical structure is very useful for mapping CBD. However, GEDI has not yet been applied for this. In this work we aim to assess a methodology for estimating CBD using GEDI. This will help to better understand forests and to develop efficient crown fire risk prevention strategies.

Methodology

We estimated CBD following García et al (2012, Remote Sens. Environ., 123), which adapted the Sando and Wick (1972) field method to ICESat/GLAS to a local area. Here we are applying it to GEDI and to a regional scale. We used GEDI L1B and L2A products from May to August 2020 at two US sites representing dry (North of Sacramento: 7240 footprints) and humid (Idaho: 7745 footprints) conditions and a wide range of fuels. We filtered for quality to ensure forest footprints. We used L2A to get ground elevation and RHs. We processed L1B to smooth the waveform to identify the energy groups of each vertical layer: ground, canopy and understory.

CBD was calculated using the gap probability models by estimating the leaf area density

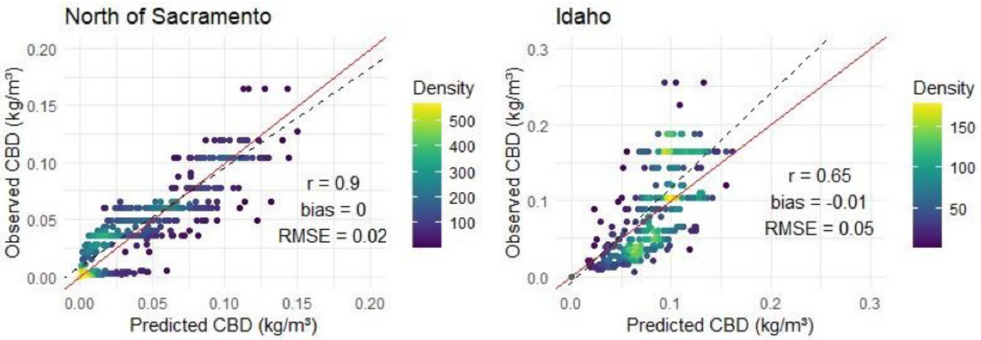
(LAD; m2/m3) adapting the Leaf Area Index (LAI; m2/m2) equation from Tang et al (2014, Remote Sens. Environ., 143). We grouped by 7 GEDI height bins to calculate the LAD at each metre. For each footprint we approximated the canopy and ground reflectivity ratio using the total LAI from Copernicus. The fuel vertical profile (FVP) was calculated by dividing the LAD values by the specific leaf area (m2/kg) from the TRY database. Finally, CBD (kg/m3) was calculated as the maximum of the smoothed FVP. We assessed the method comparing our results with US reference data from the LANDFIRE project (2020). We aggregated ours and LANDFIRE estimates to ~1 km2 by the median to overcome GEDI geolocation uncertainty error and weighted by LANDFIRE canopy cover.

Expected results

The results show that the proposed method is capable of accurately estimating CBD (Fig. 1). The observed versus predicted results yielded r = 0.65-0.90, bias = -0.01–0 and RMSE (kg/m3) = 0.02–0.05 for both study sites, which are intended to represent two different forest types: dry and humid conditions. However, for humid conditions (Idaho), it was observed an increasing bias underestimating the high CBD values (CBD > 0.2 kg/m3), suggesting that the model has some limitations to correctly derive CBD values in dense forests, which could be a matter of the GEDI's limitation for penetrating dense canopies. Systematic underestimations of CBD estimates were also observed using GLAS. Nevertheless, we consider that the proposed method for estimating CBD using GEDI data is robust enough and could be applied to obtain spatially explicit estimates of this fuel parameter. Using the median to aggregate the GEDI footprints into 1 km pixels allows to overcome the limitation of GEDI geolocation uncertainty error while preserving ground-truth values. The discrete LANDIFRE values resulted in a discontinuous distribution of observed values in the plots. Also, the GEDI's sampling acquisition mode would require aggregating the footprints into pixels to generate spatially continuous maps of CBD.

Outlook for the future

This study assesses the capability of GEDI to map CBD, crucial for understanding crown fires. The methodology would enable to produce updated CBD maps, improving forest fire prevention. This information would aid in assessing fire behavior modelling and should be complemented with maps of other canopy parameters (canopy height, cover and base height). Such data can be input for fire behavior models. Caution is advised in areas with expected high CBD, as it may be underestimated. Together with other remote sensing imagery, GEDI would allow for updated regional CBD maps in the US and other regions at circa year 2020. This work is part of the FirEUrisk project (https://fireurisk.eu/). Ongoing exploration into factors initiating and spreading fires is vital for improving forest fire prevention and management strategies. This research calls for further investigation into fire drivers to protect people and environment from their increasing negative impacts.



Observed versus predicted plots for CBD for the two sites. The red line is the 1:1 line. The dashed line is the best fit linear model to the data.

Towards Data-Driven Fire Management: from Comprehensive Fuel Characterization Data to Satellite Sensors Design

Marta Yebra[1,2,3,*], **Nicolas Younes**[1,2], **Gianluca Scortecini**[1,2]

1 The Fenner School of Environment and Society, College of Science, The Australian National University, ACT, Australia
2 Bushfire Research Centre of Excellence, The Australian National University, ACT, Australia
3 School of Engineering, College of Engineering, Computing and Cybernetics, The Australian National University, ACT, Australia

**Corresponding author:* marta.yebra@anu.edu.au

Keywords: earth observation, wildfire management, flammability traits, live fuel moisture content, hyperspectral, calibration and validation

Challenge

Forest fires are increasingly prevalent in areas historically unaffected, thus challenging current firefighting efforts. These wildfires present a grave global threat, underlining the critical importance of understanding vegetation dynamics, particularly Live Fuel Moisture Content (LFMC) and other fuel flammability traits, essential for effective wildfire management. While remote sensing data from satellites holds promise in providing a comprehensive, large-scale monitoring capability for these variables, the lack of comprehensive, openly available datasets hinders the design, calibration and validation of fit for purpose satellites and algorithms. To bridge this gap, we introduce Globe-LFMC 2.0 and EUCFLamm. Globe-LFMC 2.0 is an extensive dataset spanning 47 years and 15 countries, comprising over 280,000 LFMC measurements from diverse plant species. EUCFLamm offers a unique dataset combining detailed spectral reflectance measurements with a comprehensive suite of flammability-related physical and biochemical properties of eucalypt leaves. We illustrate the utility of these databases through two case studies: the design of OzFuel-1, an Australian satellite instrument tailored to monitor forest flammability from space with optimal spatial, temporal, spectral, and radiometric resolution; and the validation of an algorithm for LFMC estimation from Sentinel-2 imagery. These initiatives represent significant strides towards advancing LFMC and flammability research, laying the groundwork for more resilient wildfire management strategies.

Methodology

Globe-LFMC 2.0 is an extensive dataset of live fuel moisture content (LFMC) with over 280,000 measurements across more than 500 different plant species in 15 countries. Covering diverse environments like grasslands, shrublands, closed forests, and open woodlands, it offers a rich basis for research and modelling. Following the selection of locations for which the dataset offers representative LFMC samples of the observable vegetation from satellites, it can be utilised to train or validate remote sensing models for the estimation of LFMC at landscape scale across various vegetated land cover types. EUCFLamm is a unique dataset that combines detailed spectral reflectance measurements with a comprehensive suite of flammability-related physical and biochemical properties of eucalypt leaves. This dataset consists of eucalypt leaf samples collected across the Australian Capital Territory from 2021 onwards thus allowing the tracing of spectral and flammability traits over time. This dataset has directly informed the spectral and radiometric resolution of the OzFuel-1 sensor. OzFuel-1 is an Australian satellite instrument designed specifically for flammability monitoring. It will operate in the Short-Wave InfraRed (SWIR) spectrum and will monitor changes in water content, cellulose, leaf dry mass and area; volatile organic compounds (VOCs), total Carbon, Nitrogen, and Phosphorous are also being considered as target traits.

Expected results

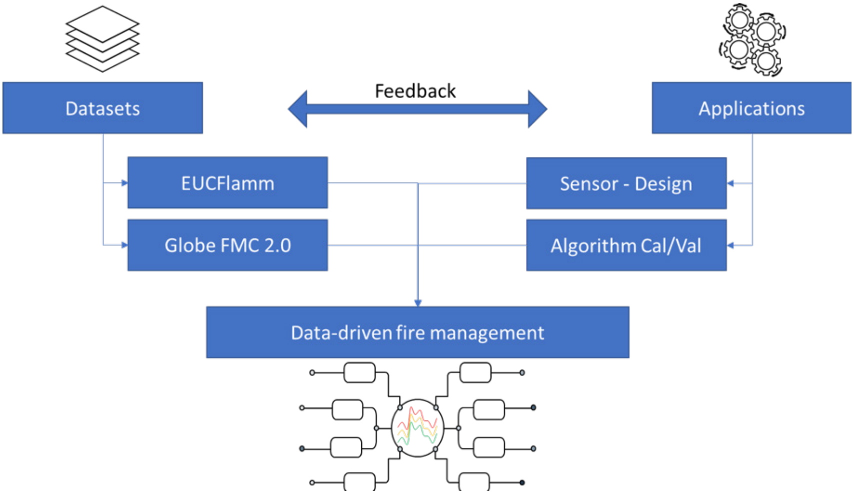
We have developed a machine learning model that utilises the high spatial resolution (~20 m) Sentinel-2 data with the objective of emulating an RTM-based model developed for MODIS data (~500 m spatial resolution). The machine learning approach enable us to overcome the obstacle of running RTMs at the Sentinel-2 scale, which would be too computationally expensive. The model employs a selection of Sentinel-2 bands, as well as land cover information. The utilisation of Globe-LFMC for the validation of the remote sensing model will have a dual benefit: it will allow us to test the accuracy of LFMC estimation, but it will also provide valuable insights on how to successfully employ the dataset for this objective, including the selection of measurements representative of the landscape vegetation. Moreover, EUCFlamm is informing OzFuel's design as well as the calibration and validation of algorithms to convert OzFuel reflectance data into actionable information on fuel flammability. To that extent, EUCFlamm is being use for spectra and image simulation. Image simulation tools mimic satellite data based on fuel properties, allowing us to test and refine OzFuel's ability to detect the areas where flammability is high.

Outlook for the future

Comprehensive vegetation fuel flammability data informs where and when fires are likely to occur and enables the design of satellite sensors as well as the calibration and validation of algorithms, and models. Both, Globe-LFMC 2.0 and EUCFlamm, offer unprecedented opportunities for advancing our understanding of vegetation flammability, as well as calibration and validation of new and existing satellite sensors. Future applications of these datasets could include:

- Inclusion of flammability in fire behaviour models, resulting in more accurate predictions of fire ignition, spread, and intensity.
- Improved accuracy in the estimation of vegetation fuel flammability from satellite sensors.
- Development and improved parametrization of Radiative Transfer Models.

Novel spaceborne sensors, improved satellite-derived models, and fuel characterization datasets will play a major role in data-driven fire management activities over the next few years.



Graphical abstract.

Integrating Phenology in Operational Early Warning for Forest Fires Using Sentinel-2 Data

Nicolò Perello[1,2,*], Andrea Trucchia[1], Mirko D'Andrea[1], Olga Parshina[3,1], Giuseppe Squicciarino[1], Luca Pulvirenti[1], Paolo Fiorucci[1]

1 *CIMA Research Foundation, Savona, Italy*
2 *Dipartimento di Informatica, Bioingegneria, Robotica e Ingegneria dei Sistemi, University of Genoa, Genova, Italy*
3 *Sapienza University of Rome - Department of Civil, Building and Environmental Engineering, Rome, Italy*

**Corresponding author:* nicolo.perello@cimafoundation.org

Keywords: earth observation, wildfire early warning system, wildfire danger, NDWI

Challenge

Forest Fire Danger Rating (FFDR) models are widely used in wildfire management, from daily operations to seasonal and long-term planning. Early warning of extreme fire danger is necessary for Civil Protection Authorities to mitigate wildfire disasters and to identify critical periods of extreme fire danger in advance. In the presented research, the FFDR RISICO, operational at national scale in Italy since 2003, has been enhanced since 2019 by using phenological indexes. To identify the phenological conditions of vegetation, the Normalized Difference Water Index (NDWI) from Sentinel 2 images, has been adopted, based on a deep analysis of several vegetation indexes. NDWI can represent seasonal transitions of deciduous and herbaceous vegetation, as well as drops in moisture content in evergreen forests and shrubs. This approach allows the transition of the FFDR system from worst-case scenarios to more informed danger forecasts. Some results related to the period 2021-2022 are presented.

Methodology

RISICO model integrates meteorological observations and forecasts provided by Limited Area Models with vegetation cover and topography as additional inputs. Its latest release, RISICO 2023, adopts a new revision of the hourly Fine Fuel Moisture Content and a new AI-informed fuel map, which becomes dynamic by including NDWI indexes. Thus, dead fine fuel moisture content, potential rate of spread and fireline intensity can be visualised as three-hourly spatial layers (with resolution of 100 m), or aggregated temporally (e.g., daily indexes) and/or spatially (at regional or district level). Concerning the phenological part, raw NDWI from Sentinel-2 is normalised in a pixel by pixel fashion, using the underlying information of vegetation maps to create a vegetation dependent indicator. The obtained indicator ranges from 0 (healthy vegetation) to 1 (dry vegetation) and it is multiplied to Rate of Spread and Fireline Intensity, acting as a limiting factor for these two outputs of the FFDR. To assess the performance of the NDWI-refined RISICO 2023 outputs, some analyses are performed for the years 2021-2022. Output of the FFDR over 11872 fires were analysed by using or not NDWI and compared with the output of the model for similar location but in absence of wildfire. The computed dataset also allowed for a ROC analysis by using the output of RISICO 2023 as a basis. The analysis has been computed for several classes of wildfires, using different thresholds of burned area.

Expected results

The analysis of RISICO 2023 behaviour over the 2021-2022 wildfires, with and without applying the NDWI factor, has been visualised through box plots for the case of pseudo-absences, random points, and wildfires. The NDWI version of both Rate of Spread and Fireline Intensity show in general lower values. However, this reduction is higher in smaller fires, and in pseudo absence fires, leading to an effective reduction of the overshoot of the danger in situations not prone to big fires due to the phenological state. An analysis of the ROC curves show that the AUC is always increasing when the NDWI correction is applied. This increase may appear modest (around 2%). However, it should be considered that RISICO 2023 has already undergone an optimization of both the fuel map module and the fine fuel moisture module, and therefore the room for drastic improvements of the performance is reduced. Contingency table analysis “size of fire versus predicted output of RISICO 2023” with fires of different size, shows that after the inclusion of NDWI, the classes of low burned areas (such as <1ha, or 1-10 ha) tend to be associated with lower danger estimates. Similar trends are observed for both Rate of Spread and Fireline Intensity when applying the NDWI corrective factor.

Outlook for the future

The performed analysis expresses the potentialities of the inclusion of vegetation indices in loop into an operational FFDR system such as RISICO 2023. Knowing the phenological state translates into a limiting factor for the danger estimates, allowing the final early warning system not to overestimate danger in the situation of healthy vegetation despite the potential severe weather. This has proven to be true for the Italian landscape in the tested years. However, the pipeline of NDWI adoption needs to be optimised further, since preliminary analysis on the update times of Sentinel-2 NDWI shows that many pixels, mostly due to cloud cover, show average update times >20 days. This calls for the design of an effective gap filling model, that should make the most out of the data of the land use/ topography/vegetation cover, of the state of near pixels, and the available time series of Sentinel-2 passages, hopefully coupled with weather-drought indices.

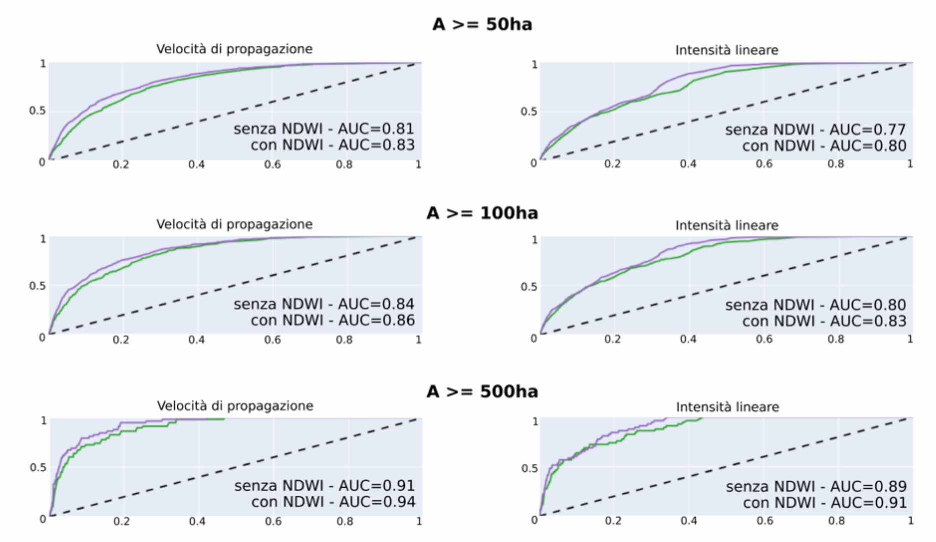


Figure 1. ROC curves with (purple) and without (green) NDWI correcting factor. The first column stands for the Rate of Spread output of RISICO 2023, while the second one stands for the Fireline Intensity output. The three rows display the analysis of respectively fires >= 50, 100, 500 ha.

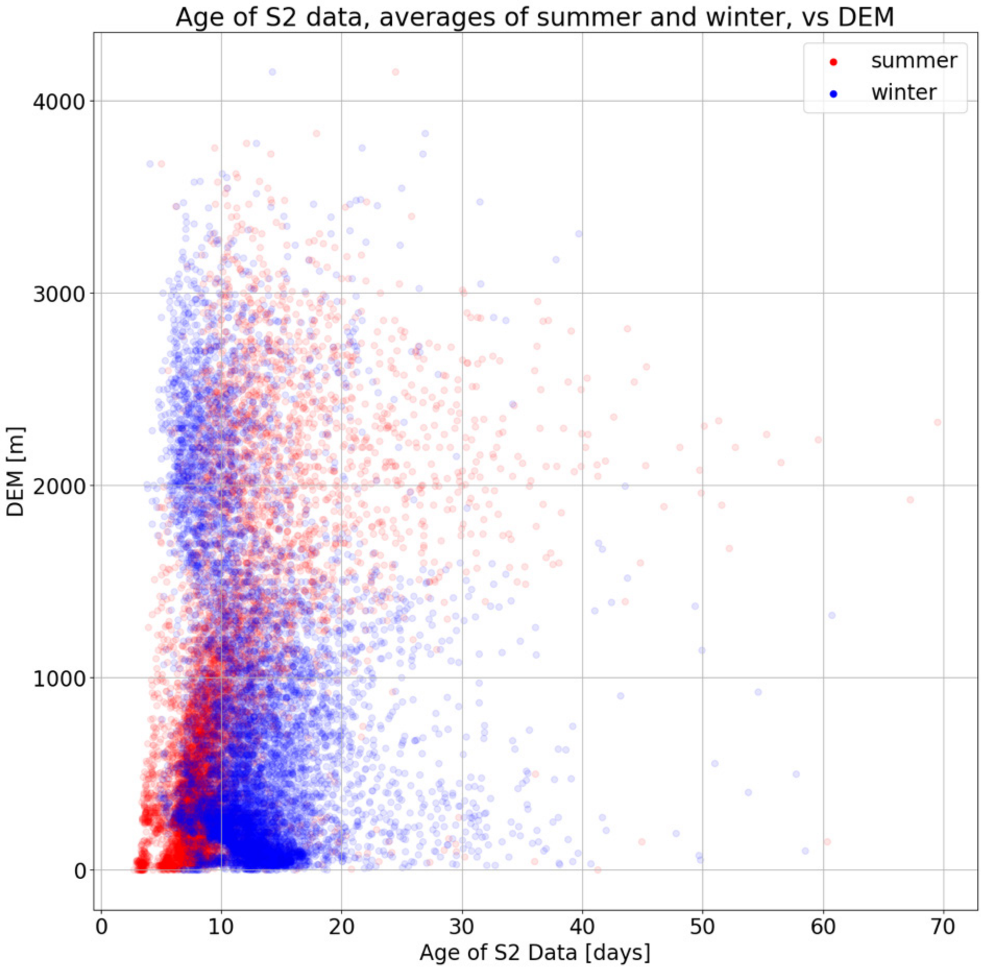


Figure 2. Analysis on the Sentinel-2 NDWI layers acquired in the years 2019- 2023, for a tile encompassing Piedmont and Liguria, separated into winter (November 1 - April 30) and summer (May 1 - October 31) layers . Distribution of the average pixel age values of the entire winter ensemble (blue points) and summer ensemble (red points). The x-axis corresponds to the values of average age of each pixel, while the y-axis refers to its elevation from DEM [m]. From the Figure we have that in summer there are more points with low age (the predominantly red cluster at the bottom left of the graph); in summer at high altitude, it is more likely to encounter pixels with high age; in winter months, the trend is opposite to what is described for the summer months.

Predicting Fire Severity in the French Mediterranean Area from Pre-Fire Time Series of Remote Sensing and Meteorological Data

Victor Penot1,*, Thomas Optiz2, François Pimont3, Olivier Merlin1

1CESBio, France
2BioSP, France
3URFM, France

**Corresponding author: victor.penot@iut-tlse3.fr*

Keywords: fire severity, optical remote sensing, meteorological data, Mediterranean area, time series

Challenge

The French Mediterranean area is subject to a high number of fires, which are expected to increase in the context of climate change. Most wildfire danger models are based on predictions of fire occurrence and area. In addition, fire severity, defined as the degree of environmental change caused by a fire, could provide valuable information. Fire severity can be assessed using indices derived from optical remote sensing, such as the Relative Burn Ratio (RBR). Recently, research has focused on predicting such indices. Immediate pre-fire predictors such as remotely sensed fuel proxies and day-of-fire meteorological data and indices are used in machine learning or statistical modelling. However, prediction of RBR remains a challenge. This study investigates for the first time the usefulness of the information provided by the fuel and meteorological forcing dynamics several months before the fire to predict RBR.

Methodology

This study examines 79 forest fires in the French Mediterranean area that occurred between June and September, from 2016 to 2021. We use time series spanning for six months before fire of the Normalized Difference Vegetation Index (NDVI) – a remotely sensed proxy of living biomass and living fuel moisture –, and of two widespread fire danger meteorological indices, namely the Duff Moisture Code (DMC) and the Drought Code (DC) – two codes rating the mid- and long-term meteorological forcing on fuel respectively. Remotely sensed data are provided by the Landsat-7/8 and Sentinel-2A/B missions, while the SAFRAN reanalysis dataset (8 km resolution) provides meteorological data. All predictors are averaged over the 179 fire– land-cover patches greater than 14 ha. We use two statistical models to assess the impact of time-series information on RBR prediction: a Functional Linear Model (FLM), whose inputs are the whole times series of predictors, and a Lagged Generalized Additive Model (LGAM), whose inputs are time-lagged. We vary the length of the time series/time-lag between 185 days and 15 days before the fire. A GAM fed with NDVI, DC and DMC measured immediately before the fire is used as a benchmark. A 10-fold cross-validation, repeated 10 times, is carried out such that training fires are independent of the test fires. We evaluate the predictive ability of the models using the correlation (R) and root mean square error (RMSE) between the predicted (test) and measured RBR.

Expected results

We show that FLM achieves the best prediction accuracies on test data (R=0.68, RMSE=0.057) compared to LGAM (R=0.60, RMSE=0.063) and to the benchmark GAM (R=0.52, RMSE=0.069). The few studies that follow the same methodology without the use of time series do not produce such good results. Moreover, FLM achieves its best prediction accuracies for a time series length of 65 days before fire, while LGAM achieves its best prediction accuracies for a time-lag of 25 days before fire. Another interesting feature of FLM is that it provides weighting functions that allow the temporal dynamics of a predictor to be interpreted in order to obtain a high or low RBR (see Figures a) and b)). NDVI time series with values above the NDVI time series mean between 65 days and 25 days before the fire, and below the NDVI time series mean between 25 days and the day of the fire give a high RBR. This faster than average decline in NDVI, with relatively high values 65 days before the fire, illustrates the dynamic processes of desiccation leading to large RBR. Consistently, DMC time series that rise faster than average and reach high day-of-fire values, and higher than average DC 65 days before fire, lead to high RBR. The temporal nature of these behaviours related to NDVI, DMC and DC may explain the difference in prediction accuracy between FLM, LGAM and GAM. Our results highlight the importance of considering the temporal dynamics of bottom-up (NDVI) and top-down controls (DMC, DC) on fire severity.

Outlook for the future

Our study provides insights into the prediction of fire severity indices, but several points could be improved in the near future. Meteorological indices that assess fire danger are coarse scale proxies for fuel moisture. However, they do not reflect locally the actual soil water storage, which can vary spatially over short distances and has a strong influence on the hydric behaviour of live fuel. To bridge the gap, recent advances in thermal remote sensing and near-term thermal missions (e.g. TRISHNA) could significantly improve the assessment of water stress. In particular, it is expected that vegetation stress indices derived from high spatial resolution thermal data will better constrain the local behaviour of the living fuel than meteorological data alone. Furthermore, our study provides results at the fire-land cover scale (>14 ha), which could be relevant for regional forecasting, but a finer spatial scale could be useful for a more accurate prediction of fire severity.

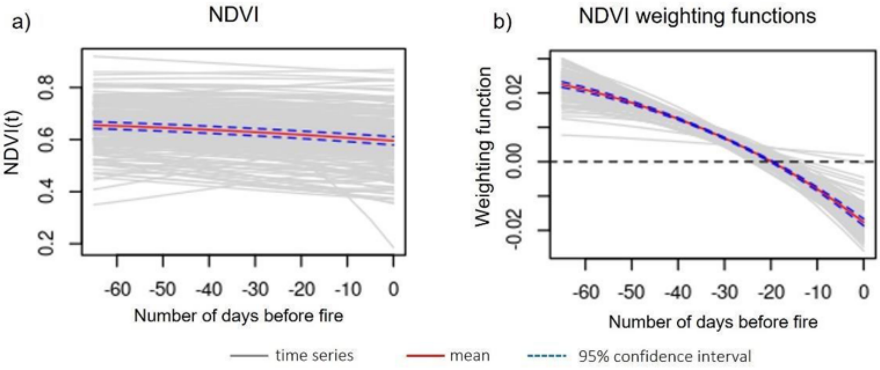


Figure a) NDVI times series of the 179 Fires—Land-Cover patches

Figure b) NDVI weighting functions of the difference between point-wise NDVI and point-wise mean NDVI. The 100 functions come from the 100 trained FLM models.

Mapping Burnt Areas and Fire Effects in Mediterranean Forests Using Machine Learning with Optical and SAR Satellite Imagery

Giandomenico De Luca[1,*], **João M.N. Silva**[2], **Giuseppe Modica**[3]

1 *Institute for BioEconomy (IBE), National Research Council of Italy (CNR), Via Madonna del Piano 10, 50145, Sesto Fiorentino, Italy*
2 *Forest Research Centre, Associate Laboratory TERRA, School of Agriculture, University of Lisbon, Tapada da Ajuda, 1349-017 Lisboa, Portugal*
3 *Department of Veterinary Science, University of Messina, Viale G. Palatucci S.N, 98168, Messina, Italy*

**Corresponding Author:* giandomenico.deluca@cnr.it

Keywords: fire detection, fire severity, post-fire vegetation assessment, post-fire recovery, Copernicus Sentinel

Challenge

Although the effectiveness of optical satellite-based remote sensing data and technique for retrieving and analyse accurate information relating to the impact of fire on the forest environment and how its effects are distributed over time and space has been widely proven, these sensors present some limitations, mainly due to their sensitivity to some environmental conditions, such as sunlight and cloud cover, which reduces the frequency of observation at the visible/infrared wavelength bands or the spectral confusion of burned areas with unburned low albedo surfaces (i.e., dark soils, water surfaces, shadow areas), or the premature signal saturation due to the high sensibility to increasing values of leaf area index (LAI). Furthermore, this type of sensors cannot capture many quantitative aspects since these wavelengths do not interact directly with the structure of the objects. Therefore, methods based on data acquired by cloud-independent and structure-dependent sensors at high spatial and temporal resolutions are needed. Among them, Synthetic Aperture Radar (SAR) are active sensors that generates their microwave impulses (2.4-100 cm) and transmits them from its antenna to a target. Calculating the amount of the signal fraction reflected back to the sensor (backscatter) characterizes the target's spectral radar signature. The penetration capacity of the impulse in the matter is directly proportional to the wavelength. For this reason, the SAR waves can pass through atmospheric particulate or interact with the vegetation cover structure. Therefore, to characterize and quantify the effects of a disturbance on vegetation, SAR technology exploits the variations in backscatter caused by the modification of the vegetation cover and soil's structure and moisture content. However, its processing and interpretation complexity causes this sensor not to be widely used compared to optical ones.

Methodology

The present work, based on the results of several studies conducted on multiple study areas in Italy and Portugal, proposes a complete remote sensing-based workflow aimed at investigating and mapping the short-term effects of fire on Mediterranean forest and semi-natural ecosystems and monitoring the vegetation response during the first years after the fire event. In particular, the following objectives were attained: 1) characterization of pre-fire conditions; 2) burned area mapping; 3) estimation and mapping of fire severity; 4) monitoring of post-fire recovery.

To fulfil these objectives, machine learning algorithms were applied to satellite data, namely multispectral optical (Sentinel-2) and synthetic aperture radar (SAR; Sentinel-1) imagery, with high spatial and temporal resolution and freely provided by the European Space Agency (ESA). Specifically, the four phases were developed as follows:

a) Creation of an accurate land cover and land use map in order to have a quantitative-qualitative overview of the vegetation present before the fire event. Several variables were calculated and used as informative input dat. In particular, the time-series of SAR S1 backscatter (both VH and VV polarizations) and two derived indices, radar vegetation index (RVI) and radar forest degradation index (RFDI), were combined to the time-series of the optical S2 bands and three derived VIs: NDVI, NDRE, and NBR. In order to optimize the classification procedure, the coherence measure coming from InSAR analysis was also added as additional information, as well as the optical-based biophysical variables fraction of green vegetation cover (fCOVER), the fraction of absorbed photosynthetically active radiation (fAPAR), and the leaf area index (LAI) calculated for the same month. The well-known Random Forests (RF) machine learning algorithm was applied for classification. An exhaustive grid search analysis was applied to set the optimal parameters of a random forest classification model.

b) Accurate mapping of burned areas and delimitation of their perimeters. Two approaches have been compared. The first concerned only using SAR data for unsupervised detection of burned areas, conducted via the k-means algorithm (set using a silhouette analysis). The spectral contrast between changed and unchanged areas was enhanced by calculating two single-polarization radar indices: the radar burn difference (RBD) and the logarithmic radar burn ratio (LogRBR); and two temporal differences of dual-polarimetric indices: the delta modified radar vegetation index (ΔRVI) and the delta dual-polarization SAR vegetation index (ΔDPSVI), all exhibiting greater sensitivity to the backscatter changes. The scene's contrast was enhanced by extracting the Gray Level Co-occurrence Matrix (GLCM) textures (dissimilarity, entropy, correlation, mean, and variance). A principal component analysis (PCA) was applied for reducing the number of the GLCM image layers. In a second approach, a multi-temporal composite image process was proposed, combining both Sentinel-2 and Sentinel-1 images, to map the areas burned at a regional/national scale by fires that occurred during an entire fire season. In particular, the second-lowest near infra-red (NIR) image composite (secMinNIR) criterion, based on the retrieval of the second minimum values that the NIR values reached in each pixel during the entire time frame considered, was applied to cloud-free S2 imagery to optimize the separability between burned and unburned areas. Subsequently, a second temporal composite criterion was developed and applied to the S1 time series, relying on the SAR capacity to detect vegetation fire- induced structural and humidity changes. It was based on retrieving the S1 pixel value of the first next (or the same) date to the corresponding date of the pixel value previously found by secMinNIR. The burned area map was created using an object-based geographic analysis (GEOBIA) process, using two optical and SAR composite images as input layers. The large-scale mean-shift (LSMS) algorithm was employed to segment the image, while the RF classifier was the machine-learning model used to perform supervised classification. GEOBIA-based burned area classification was also performed using only the optical composite.

c) Estimating and mapping short-term fire effects, namely fire severity. Two approaches were presented: the first one was based on the use of the Composite Burnt Index (CBI) protocol to determine in-field the severity classes used to define the training data of the classification model. First testing a RF classifier, comparing the use of optical-only or SAR-only data with their integration (optical+SAR). Subsequently, also an artificial neural network (ANN) was tested on optical data only. A second approach involved the application of a linear spectral mixture analysis (LSMA) technique on Sentinel-2 for the spectral characterization and proportional quantification of three main physical effects found immediately after a forest fire. The tree crowns fire damage was subsequently mapped, integrating fractional abundance information in a RF algorithm.

d) For the first years after a fire event, the investigation of temporal and spatial dynamics of the post-fire recovery of different Mediterranean vegetation types characterized the fourth step. Both SAR Sentinel-1 and optical Sentinel-2 time series were analyzed separately according to the fire severity classes (obtained in the previous step), highlighting the complementary and essentiality of both information. Moreover, a burn recovery ratio (BRR), optimized through machine learning regressors for predicting pre-fire conditions, was proposed to estimate and map the spatial distribution of the degree of vegetation recovery.

The entire process was developed and executed using freely available data and open-source software (e.g., ESA SNAP, OrfeoToolbox, Scikit-learn), and libraries were implemented primarily using Python.

Results

Accurate and tempestive information about the impacts of the fire on the environment, how its effects are distributed over time and space, and what is the response of the environment during the subsequent years after the event, are therefore of primary importance to predict and manage post-fire processes, in order to mitigate the degradation of forests and, landscapes, and the loss of ecosystem services. these purposes have been fulfilled by proposing several case studies constituting a complete open-source workflow for post-fire assessment, based on remote sensing data and geo-informatic techniques. In particular, the potential of the integrated use of SAR (Sentinel-1) and optical (Sentinel-2) free-available satellite data was explored, while emphasis was placed on the implementation of advanced open-source machine/deep learning.

The main outcomes of the four steps can be summarized as follow:

1. The first step, focused on the quantification and mapping of the vegetation condition before the fire event, and relying on the integration of optical land SAR data, allowed to achieve an overall accuracy (F-score) of 0.903 when SAR was coupled with optical information, that is an improvement of 2.53% compared to when only optical data was used.
2. Assessing the accuracy of the resulting detected burned areas using only SAR data, an official burned area map based on multispectral Sentinel-2 (S-2) was used for PO, while for IT, a reference map was produced from S-2 data, based on the normalized burned ratio difference (ΔNBR) index. Recall (r), precision (p) and the F-score accuracy metrics were calculated. Our approach reached

the values of 0.805 (p), 0.801 (r) and 0.803 (F-score) for PO, and 0.851 (p), 0.856 (r) and 0.853 (F-score) for IT.

The multi-temporal composite image process combining both Sentinel-2 and Sentinel-1 and subsequent object classification (GEOBIA) to map the areas burned on a regional/national scale by fires that occurred during an entire fire season, reached F-score values of 0.914 using only optical data and 0.956 combining optical and SAR.

3. First testing a RF model, a F-score value of 0.838 was achieved when both datasets were combined (Sentinel-1 and Sentinel-2), compared to values obtained using SAR (0.513) or optical (0.805) only. The results obtained from testing an artificial neural network with only optical data (F-score > 0.95) demonstrated the significant potential of adopting these advanced deep learning models. Beside the high accuracy level reached (F-score ≥ 0.90), the SMA-based approach enabled the quantification of fire-related components (charred and scorched vegetation) at pixel level. The environmental heterogeneity of the study areas affected the fire severity gradients, with a prevalence of the charred (PT) (45–46%) and green class (IT) (44–53%).
4. The post-fire temporal analysis highlighted the adaptation to fire of Mediterranean forest and shrub/herbaceous species, with high efficiency in restoring the vegetation cover. Differently, the ecological vulnerability of non-native eucalyptus plantations was found in a lower recovery trend during the observation period. The use of optical short-wave infrared (SWIR) and SAR C-band-based data revealed that some ecological characteristics, such as the woody biomass and structure, recovered at slower rates, comparing to those suggested by using near-infrared (NIR) and red-edge data.

As a final outcome, although optical information has been sufficient for early burned areas and fire-severity mapping (excluding cloudy-sky conditions), since the increase accuracy given by SAR is negligeable compared to the amount of pre-processing it requires, the latter data resulted an important complementary information to better comprehend the physical effects of fire on vegetation.

Outlook for the future

The post-fire recovery dynamics of Mediterranean ecosystems, as well as the ecological strategies that vegetation species set up after wildfires (or other disturbances) occur, should be further examined in long-term monitoring protocols in this and other study areas to assess the complete response, even of delayed effects. Moreover, additional indicators and sensors may be necessary to determine which combination of temporal patterns best reflect the real post-fire dynamics in the Mediterranean ecosystems and their chemical, physiological and structural features. Focusing on SAR data, medium-long term monitoring may require the integration of multifrequency techniques with longer wavelengths (L-, P-band), able to penetrate further into the regenerated canopy, thus enabling better understanding of forest recovery processes. For this last aspect, it is assumed that the imminent availability of new free-available data (e.g., ESA ROSE-L mission) will optimize the performance and the already high inter-compatibility of these resources.

Further emphasis will involve advanced machine/deep learning regression models to predict temporal and spatial recovery patterns, basing the regression on the values of the recovery metrics calculated. In this regard, we believe our results will efficiently provide helpful information processing algorithms for their modelling. In particular, a novelty contribution provided by this study concerns the use of machine learning-based regression to optimize post-fire monitoring by reconstruction of fire affected pixels (reconstruction the hypothetical conditions of fire-affected areas as if the fire had not occurred) so as to account natural phenological temporal contribution to temporal spectral signatures. More experiments might be implemented to further optimize this aspect, also integrating the exploitation of deep learning architectures to construct prediction models for post-stress behaviour of ecosystems.

Characterizing Fuel Types, Loadings and Fire Behaviour in Central European Forests Using a Combination of Proximate and Remote Sensing Techniques

Pia Labenski[1], Michael Ewald[1], Sebastian Schmidtlein[1], Fabian E. Fassnacht[2,*]

1 Karlsruhe Institute of Technology (KIT), Institute of Geography and Geoecology, Germany
2 Freie Universität Berlin, Remote Sensing and Geoinformatics, Germany

* *Corresponding Author:* fabian.fassnacht@fu-berlin.de

Keywords: sentinel-2, deep learning, fuel types, forest photographs, proximate sensing

Challenge

With climate change and related longer drought periods wildfires are becoming more common also in areas that were formerly not considered to be particularly prone to fires. For example, Central European forests have experienced only few fire events in the past and mostly only small areas have been affected. In the face of the expected increase in forest fire frequency and intensity, there is a need to develop and establish fuel type classifications and approaches to inventory fuel types, quantify fuel loads and study potential fire behaviour. Such approaches will help to create baseline information for fire management as well as fire modelling which is less well-established in Central Europe compared to other parts of the world. Mapping fuel types in the field is time-intensive and remote sensing has been suggested as a potential alternative. However, current methods still leave a lot of space for improvement and collection of reference information in the field is still challenging.

Methodology

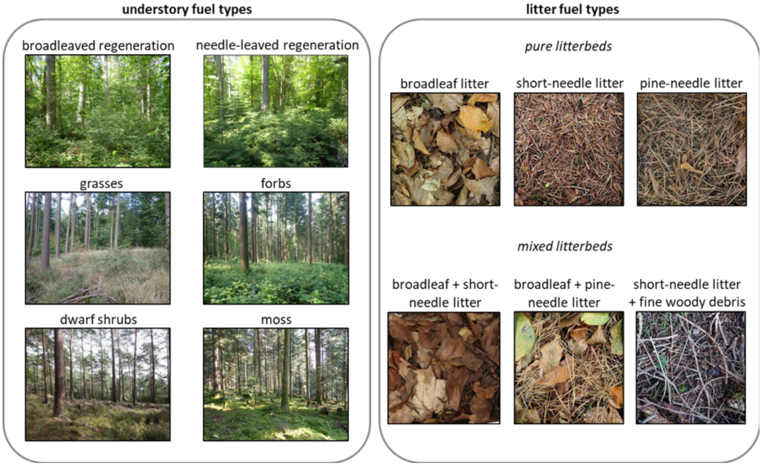
In this contribution we summarize the results of three studies which aimed on developing new work-flows to inventory and characterize fuels and fuel types in Central European forests. In a first study, we developed a work-flow which applies convolutional neural networks to classify (litter and understorey) fuel types from geo-tagged in-field photographs. The photographs were supplemented with information from Sentinel-2 time series which were analysed using long short-term memory neural networks. In the second study, we aimed to estimate fuel loads for various surface fuel components including woody debris, leaf litter and live fuels. Fuel loads were estimated using random forest, a combination of high-density airborne laserscanning data and multispectral satellite data. Additionally, we assessed whether and how the remote-sensing based fuel type maps of different fuel components affected fire behaviour predicted by Rothermel's fire behaviour model. In the third study we examined the combustion properties of leaf litter for seven common Central European tree species. Combustion properties (total heat and peak, heat release rate, flaming duration, and time to ignition) were acquired for mono-specific as well as mixed disturbed leaf litter samples using a cone calorimeter.

Expected results

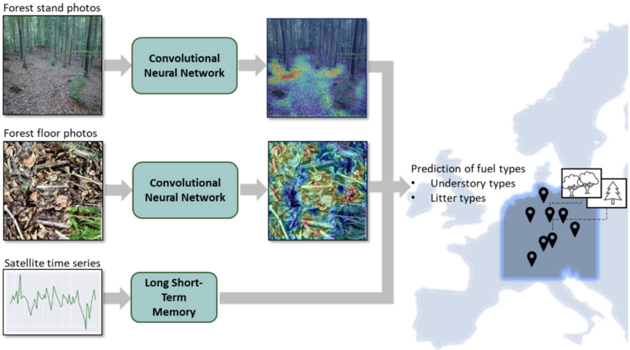
The combination of in-field-photographs and Sentinel-2 time series data led to relatively high cross-validated accuracies of approximately 85% for the classification of understory fuel types. Litter fuel types were classified with good accuracies of 72%. Most of the misclassifications that we observed were related to the naturally smooth transitions between the defined fuel type classes and the fact that often multiple fuel elements typical for a given fuel type class were occurring in a single photograph. In the second study focusing on fuel quantification, we were able to obtain overall moderately precise estimates which were fairly accurate for herb and shrub fuel loads (R^2 0.55-0.64) but more limited for shrub fine fuels ($R^2=0.39$) and fine dead woody fuels (R^2 0.27-0.41). We observed that remote sensing data only provided very limited benefits for estimating litter and fine woody fuel estimates when compared to estimates where only an average field-based fuel load value was assigned to each forest type. The study also showed that the comparably poor performance of the remote sensing-based models for predicting litter and shrub fuel loads could be problematic in fire behaviour modelling since the Rothermel model outputs showed high sensitivity for these inputs. Finally, for the leaf litter combustion experiment we observed highest total and peak heat release for pine needles while broadleaf litter showed highest ignitability and short needles had the longest flaming duration.

Outlook for the future

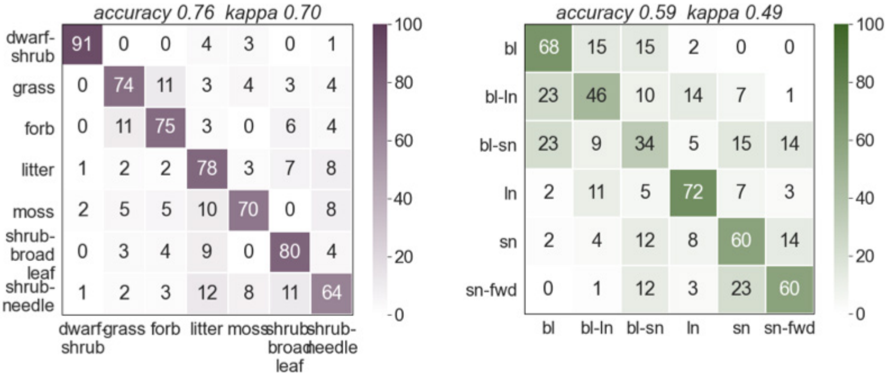
Our studies show that current developments in the field of artificial intelligence and particularly deep learning hold promise to make significant contribution to rapidly characterize fuel situations in the field. Due to the simplicity of the data needs (geo-tagged photographs) the suggested approach could enable to collect comparably large amounts of data in short time. Data collection could also be conducted by untrained staff or interested citizens. In combination with the new knowledge on combustion properties, the suggested approach may provide spatially explicit information on potential fire behaviour in Central European forests to forest managers and fire fighters. This is of particular interest since area-wide fuel load estimations from remotely sensed sources are still challenging, even when very high quality laser scanning data is available as shown in the second study.



Developed fuel-type classification for central European forests.



Methodical work-flow for fuel type classification based on field-photographs and remote sensing data.



accuracy 0.76 kappa 0.70

	dwarf-shrub	grass	forb	litter	moss	shrub-broad leaf	shrub-needle
dwarf-shrub	91	0	0	4	3	0	1
grass	0	74	11	3	4	3	4
forb	0	11	75	3	0	6	4
litter	1	2	2	78	3	7	8
moss	2	5	5	10	70	0	8
shrub-broad leaf	0	3	4	9	0	80	4
shrub-needle	1	2	3	12	8	11	64

accuracy 0.59 kappa 0.49

	bl	bl-ln	bl-sn	ln	sn	sn-fwd
bl	68	15	15	2	0	0
bl-ln	23	46	10	14	7	1
bl-sn	23	9	34	5	15	14
ln	2	11	5	72	7	3
sn	2	4	12	8	60	14
sn-fwd	0	1	12	3	23	60

Confusion matrices for classifying understory and litter fuel-types using in-field photographs, Sentinel-2 time series and deep learning. bl = broadlaved, ln=long needle, sn=short needle, fwd = fine woody debris.

EUMETSAT Efforts to Establish The European (NRT) Satellite Constellation: Observations of Wildfire Events With FCI's New Imaging Capabilities, Validation of EUMETSAT's FIR Active Fires Monitoring Product and Current Status of the Sentinel-3 NRT FRP Product

Andrea Meraner[1,*], Julien Chimot[1], Johan Strandgren[1], Hans-Joachim Lutz[1], Alessandro Burini[1], Sauli Joro[1], Bojan Bojkov[1]

1 EUMETSAT, Germany

**Corresponding Author* andrea.meraner@eumetsat.int

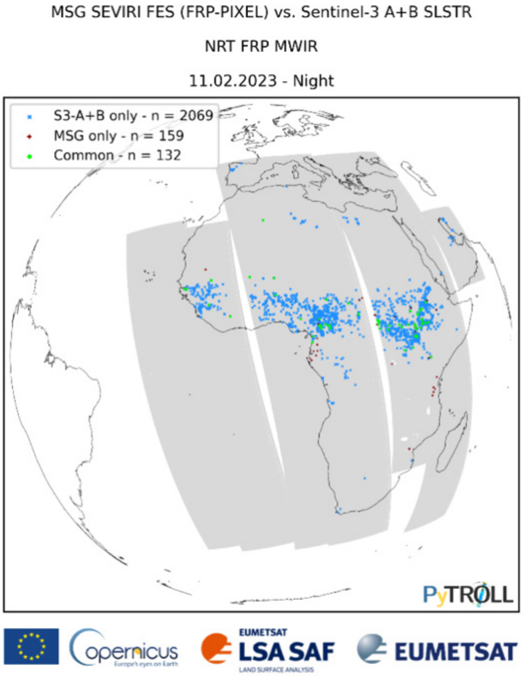
Keywords: active fire detection, fire radiative power, MTG-FCI, Sentinel-3, validation

Challenge

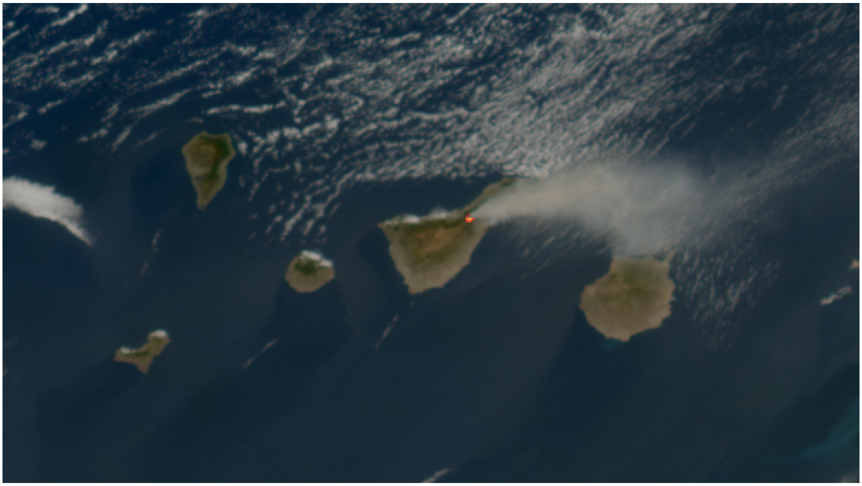
After two summers of observing wildfires with the new Meteosat Third Generation – Flexible Combined Imager (MTG-FCI), we present an assessment of its capabilities in hotspot detection and monitoring. Leveraging the improved spatial and spectral resolution, as well as radiometric quality, we analyse observations of wildfires, volcano eruptions and gas flares, discussing the sensing improvements compared to the predecessor MSG-SEVIRI instrument.

Furthermore, we report on the tuning and validation of EUMETSAT's Central Facility Level-2 FIR active fire detection product, which is operationally disseminated from FCI data. The discussion then outlines plans for future improvements and developments in fire products to fully exploit FCI's capabilities.

To conclude and complement this study, we present the current status of the Sentinel-3 NRT Fire Radiative Product, which is also generated and disseminated operationally at EUMETSAT, and the common efforts for multi-mission algorithm development and validation.



Example of output from the common validation framework developed for MTG-FCI and Sentinel-3 at EUMETSAT.



Example of fire detection and visualisation from MTG-FCI data (Tenerife, 16/08/2023, 13:30 UTC).

A proposed evaluation Framework on Quality Assurance for EO-based fire products

Bernardo Mota[1,*], **Louis Giglio**[2]

1 National Physical Laboratory, Climate & Earth Observation, UK
2 University of Maryland, Department Geographical Sciences, USA

**Corresponding author:* bernardo.mota@npl.co.uk

Keywords: earth observation, quality assurance, validation, uncertainty

Challenge

Over the past decades successful Earth Observation satellite missions made the development of global fire products possible. Currently, there are more than 40 burned area, active fire, and fire radiative power products, that tracked fire activity for decades. In addition to other applications, the information these products provide has helped characterize fire regimes, better understand the role of fire in the carbon and energy cycle, manage the landscape, and support emergency services. Quality Assurance (QA) has generally not been addressed, and developers typically focus on product validation, either through field work or intercomparison exercises, to ensure its truthfulness. However, this aspect only addresses completeness, and products need to be assessed metrologically for consistency, comparability, accuracy, and transparency. There is no standard or quality framework for which EO-based fire products can be evaluated and inform users of its fitness for purpose.

Methodology

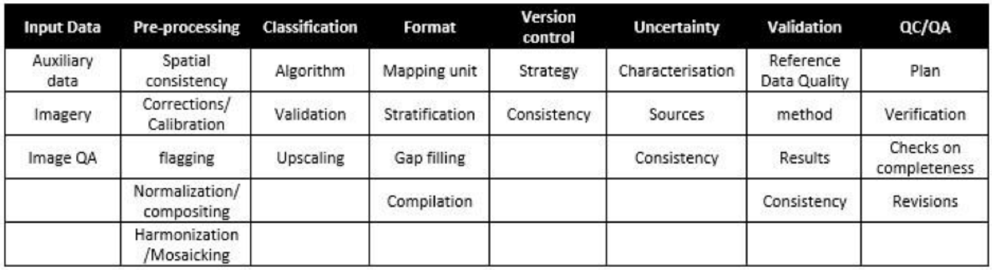
The rapid growth in the number of operational satellite missions combined with cloud-storable freely data, and the advances in machine learning methods to supplement or replace algorithm development, has led to a proliferation of fire products. Recognizing that this accelerated pace could potentially compromise product quality, space agencies in collaboration with the Cal/Val community have invested and supported several research activities, with an emphasis on the need for evaluation standards and to establish full traceability to SI: the fiducial reference measurements. Many of these developments have been addressing satellite sensor measurements at L1, and application to the downstream products has been slow for some ECVs, namely for fire products: Burned Area (BA) and Fire Radiative Power (FRP). This paper capitalizes on such activities, bringing together many of the concepts that have been developed to address all quality components, and adapted to define a Quality Measuring System (QMS) to assess the quality, and maturity, of either BA or FRP products. We will provide an overview of the key contributing project, such as the Quality Assurance framework for Earth Observation (QA4EO), Quality Assurance for ECV (QA4ECV), Copernicus climate services Evaluation and quality control (C3S EQS) and the ESA Earthnet Data Assessment Pilot (EDAP), in how uncertainty characterization, product maturity, and the evaluation framework could be processed.

Expected results

The proposed QMS framework relies on the evaluation of each product performance and compliance according to the following eight sections: Input Data, Pre-processing, Classification, Format, Version Control, Uncertainty, Validation, and QC/QA (Table 1). Each section is then divided into sub-sections, addressing the different aspects of the data product that should be evaluated and graded, either as Basic, Intermediate, Good, Excellent, or not assessed (Table 2). The combined evaluation details can be gathered in a report and summarised in a product quality evaluation matrix, quickly illustrating the level of maturity, and informing users if a particular product is ‘fit for purpose’ within the context of its application requirements. The proposed preliminary grading system is developed to address the levels of quality compliance in the context of what are the fire product’s (BA or FRP) processing requirements and characteristics. It is intended to reflect a near ‘ideal’ scenario, and serve as aspiration to new product providers, and to drive further improvements. However, it is understood that many of the providers will only be able to partly, or to different degrees, assess the product with the defined grading. In this presentation we will show examples for what could be some of the grading requirements, namely in the case of uncertainty and validation, and show results of an operational product evaluation.

Outlook for the future

We propose a Quality Measuring System (QMS) to assess EO-based fire products based on metrological principles and concepts, adapted from operational systems to evaluate upstream satellite product. This paper aims to contribute to the discussion within the fire community and product providers of what the quality requirements should be, to ensure that fire products are fully characterized, retrievals are traceable, validated, and interoperable. Only by promoting such discussion can community agree guidelines for best practices be defined and tools be developed. Such is the case for the Committee on Earth Observation Satellites (CEOS) Land Product Validation (LPV) protocols and Cal/Val portal, for which the outputs of this paper will be directed.



Input Data	Pre-processing	Classification	Format	Version control	Uncertainty	Validation	QC/QA
Auxiliary data	Spatial consistency	Algorithm	Mapping unit	Strategy	Characterisation	Reference Data Quality	Plan
Imagery	Corrections/ Calibration	Validation	Stratification	Consistency	Sources	method	Verification
Image QA	flagging	Upscaling	Gap filling		Consistency	Results	Checks on completeness
	Normalization/ compositing		Compilation			Consistency	Revisions
	Harmonization /Mosaicking						

Table 1 Maturity Matrix sections of the Quality Measurement System to assess the quality, and track improvements of either the EO-based Burned Area or Fire Radiative Power products.

Key
Not Assessed/Not Applicable
Not Assessable
Poor
Basic
Good
Excellent

Table 2 Classification key to evaluate the product compliance in each section of the maturity matrix.

A Comparative Analysis of a New Long-Term Burned Area Product and High-Resolution Burned Area Datasets

Jaime González-Delgado[1,*], Consuelo Gonzalo-Martín[1], Ángel García-Pedrero[1], Meryeme Boumahdi [1] and Mario Lillo-Saavedra[2]

1 Centro de Tecnología Biomédica, Universidad Politécnica de Madrid, Madrid, España
2 Facultad de Ingeniería Agrícola, Universidad de Concepción, Chile

**Corresponding author:* consuelo.gonzalo@upm.es

Keywords: burned area, fires, climate change, BARD, NBAC, MAPBIOMAS

Challenge

Various grid burned area (BA) products derived from satellite data exist, such as FireCCILT11, FireCCI51, MCD641, and GFED4, with differing temporal extents and estimates. Uncertainty in global BA estimates persists due to factors like coarse spatial resolution and short time series. Extending datasets to the 1980s, as recommended by GCOS, is vital for users like atmospheric and carbon modelers. Establishing consistent historical records is crucial for understanding the link between human activities, climate change, and fire behaviour. Harmonizing BA products is essential for data consistency and reliability, facilitating scientific research. One aim of the FireCCI+ project is to create a grid global long-term BA series, called FireCCIM10, spanning from 1982 to 2018, with accuracy comparable to existing short time series products. To assure its use for seamless reliable trend analysis in climate change studies, its validation is mandatory.

Methodology

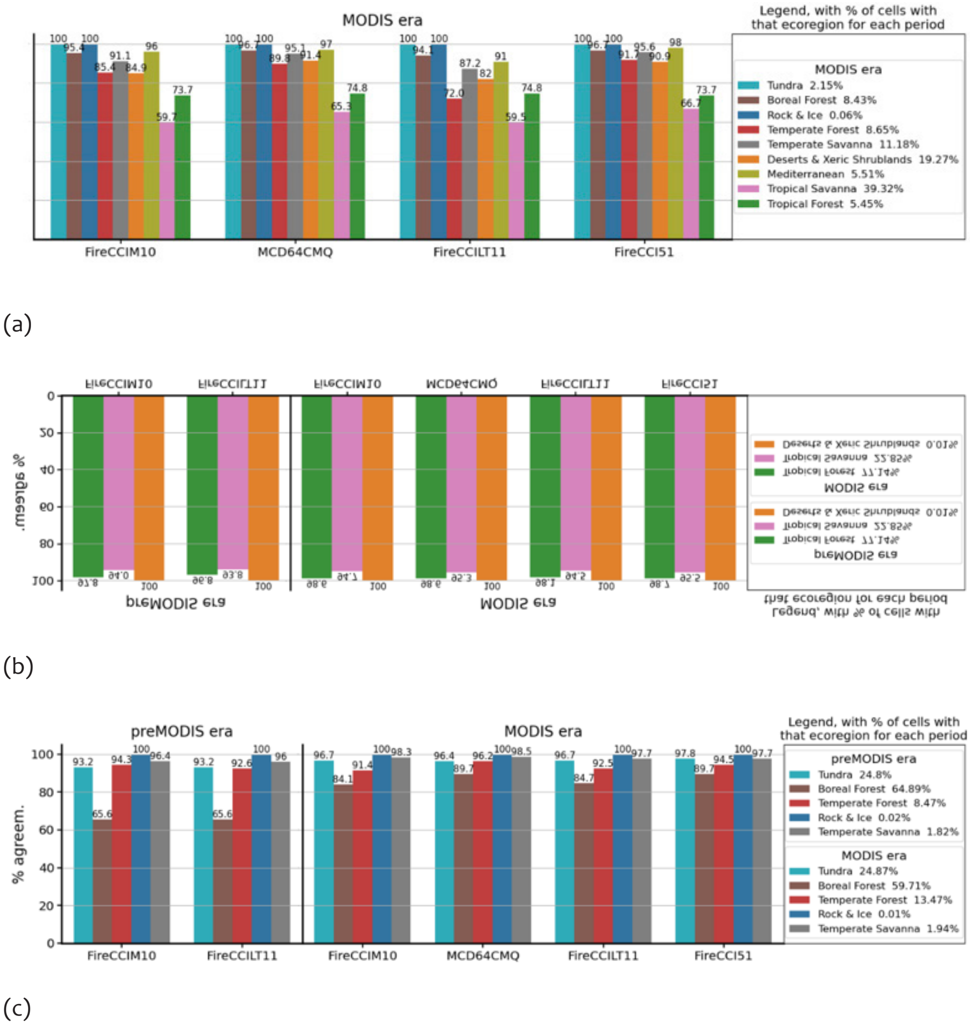
To validate the FireCCIM10 product, an exhaustive comparison was conducted with BA estimates from global and local BA references (BARD, NBAC and MAPBIOMAS) that have a higher spatial resolution. Achieving this required meticulous harmonization between FireCCIM10 and the reference databases. The process involved analyzing the reference databases to identify sets of representative cells from different biomes. These representative cells were chosen based on specific criteria, ensuring they fully covered grid cells, corresponded to unique biomes, and were not categorized as "no data". The comparative analysis was carried out on a cell-by-cell basis, examining both spatial and temporal aspects of BA estimates. The spatial comparison involved generating difference maps to visualize discrepancies between FireCCIM10 and the reference products. The temporal comparison was conducted at different levels of aggregation, including monthly and annual averages, to assess consistency over time. The results were analyzed across two distinct periods: the pre-MODIS era (1982-2000) and the MODIS era (2001-2018). This division allowed for an in-depth examination of how FireCCIM10 performed relative to reference products across different time frames. Spatial and temporal variations were scrutinized to understand any discrepancies and assess the reliability of FireCCIM10.

Expected results

The expected results of applying this methodology would include insights into the reliability of the FireCCIM10 product compared to the reference datasets (BARD, NBAC, and MAPBIOMAS). Spatial validation via difference maps enabled visual identification of discrepancies between FireCCIM10 and the reference products, illuminating areas of agreement and divergence. The temporal comparison, encompassing monthly and annual averages, assessed the consistency of FireCCIM10's BA estimates over time. Results were scrutinized across two distinct periods, pre-MODIS and MODIS eras, allowing for a nuanced understanding of FireCCIM10's performance across different temporal contexts. The analysis aimed to uncover spatial and temporal variations, offering insights into the accuracy and reliability of FireCCIM10. By systematically comparing FireCCIM10 with established reference datasets, the study provided valuable feedback on the model's strengths and weaknesses. This evaluation contributes to the ongoing refinement of BA mapping methodologies, ultimately enhancing the reliability of global fire dynamics assessments.

Outlook for the future

Through this rigorous comparison process, insights were gained into the strengths and limitations of FireCCIM10. By comparing it with established reference products, the study provided valuable information on the accuracy and consistency of FireCCIM10's BA estimates spatially and temporally. That information will be used as feedback in the generation process of FireCCIM10 with the goal of refining this BA product.



Percentage of agreement between each reference database and the BA products. (a) BARD; (b) MAPBIOMAS; (c) NBAC.

Validation of Regional and Global FireCCI Burned Area Products

Daniela Stroppiana[1,*], Erika Solano Romero[2], Amin Khairoun[2], Bhogendra Mishra[1], M. Lucrecia Pettinari[2], Emilio Chuvieco[2]

1 CNR, Istituto per il Rilevamento Elettromagnetico dell'Ambiente (IREA), Milano, Italy
2 Universidad de Alcalá, Environmental Remote Sensing Research Group, Department of Geology, Geography and the Environment, Alcalá de Henares, Spain

**Corresponding author:* stroppiana.d@irea.cnr.it

Keywords: sentinel data, wildfires, accuracy assessment, omission, commission, reference datasets

Challenge

Earth Observation (EO) is a major source of data for delivering regional to global Burned Area (BA) products, which depict the spatio-temporal distribution of wildfires to assess their impacts on ecosystems and society. Validation is the assessment of spatio-temporal accuracy of remotely sensed products by comparison with reference data, that is assumed to represent the ground-truth. Over large areas (global, continental, and regional scales) systematic collection of representatives in situ fire data is not feasible and reference datasets are built interactively from EO data such as Landsat and Sentinel-2. This work presents the validation activities of the ESA FireCCI project for assessing the accuracy of Burned Area (BA) products (FireCCISFDL, FireCCI51, and FireCCIS311) derived at regional and global scales from EO data. This validation process is essential for developers to improve product versions and helps end-users understand product limitations.

Methodology

Validation is carried out by comparison of the BA product with fire reference perimeters derived over validation units, with each unit covering an area of 100 km x 100 km (the spatial extent where the reference and the product are compared). Temporally, we define long units as the time series of source images used for deriving the reference perimeters (Landsat and/or Sentinel-2). The time series over each unit is composed of consecutive images where each image pair (i.e., short unit) is classified to extract burned polygons. Validation units are identified by stratified random sampling. The burned polygons preserve as date of burning the acquisition date of the short unit and are assumed to be burned only once within the time span covered by the long unit. The comparison is carried out by sampling the BA product between the first and last date of the period covered by the long unit. For each unit, we derived a confusion matrix and accuracy metrics (omission and commission errors, Dice coefficient, Relative Bias). FireCCI51 and FireCCIS311 are globally evaluated burned area products, annually validated using about 100 validation units (VU). FireCCISFDL BA, derived from Landsat data (1990-2019), offers high-resolution multi-annual coverage for three Regions Of Interest (ROIs): Africa-Sahel (AF) (35 VU), South AmericaAmazonia (SA) (29 VU), and Russia-Siberia (SI) (26 VU). Validation involved comparing FireCCISFDL results with Landsat and Sentinel-2 fire areas across the ROIs.

Expected results

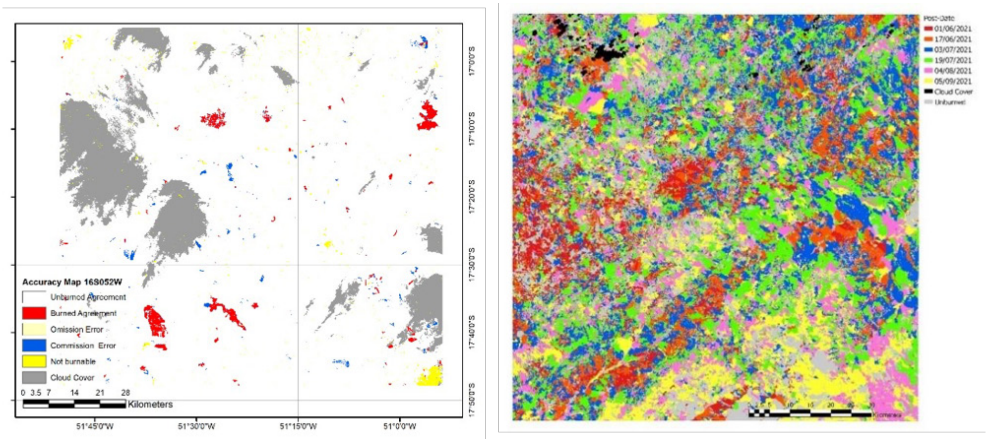
For the FireCCISFDL BA product, we derived confusion matrices and accuracy metrics for each validation unit in the ROIs and overall (all units pooled together for each ROI). These global values represent the overall accuracy of the product over the period covered (1990-2019) since the validation units (and reference fire perimeters) are distributed over time. The accuracy metrics can be discussed as a function of those factors that could influence burned area characteristics and mapping such as land cover (ESACCI-HRLC). Moreover, accuracy metrics will be analysed as a function of time (year) to investigate temporal stability of the BA product.

Furthermore, our study aims to assess the overall performance of the FireCCI51 (2017-2021) and FireCCIS311 (2019-2022) products. We will present metrics derived from the confusion matrix up to 2022, enabling a comparison of the products' performance across all years within the specified periods. This comprehensive analysis will provide insights into performance trends over time and across 8 distinct biomes globally. Additionally, we will conduct an in-depth intercomparison of these metrics to evaluate their consistency and variability over the evaluation period.

Outlook for the future

The work presented in this abstract focuses mainly on the assessment of spatial accuracy of BA products (thematic agreement that is whether the pixel is burned/unburned according to the reference); the temporal accuracy should be evaluated separately by comparison with reference data that provide accurate detection of the fire date. We will use active fire detection to assess the temporal accuracy of burned area mapping and to evaluate how date mismatch between burn date in the reference and BA products can influence the estimation of accuracy metrics.

In addition, we intend to integrate validation into results from the Global Small Fire Database Adaptation (Global SFD) algorithm currently being carried out within the FireCCI project for the year 2021. This will enable a comparative analysis of its performance concerning FireCCI51 and FireCCIS311 products. Our future focus is exploring factors affecting temporal accuracy variation to refine the validation protocol.



(a) (b)

(a) Agreement map for tile 16S052W in the Amazonia-South America ROI; (b) Example of reference fire perimeters extracted over L8 frame 173/066 (Path/Row) concerning the date of detection (colour of the polygons). Black regions are regions masked for cloud cover and grey areas are unburned

Intecomparison and Validation of the MODIS and VIIRS Global Burned Area Products

Luigi Boschetti[1,*], David Roy[2], Louis Giglio[3], Vladyslav Oles[1]

1 University of Idaho, Department of Forest Rangeland and Fire Sciences, USA
2 Michigan State University, USA
3 University of Maryland, USA

Corresponding author: luigi@uidaho.edu

Keywords: MODIS, VIIRS, validation, global products, burned area

Challenge

The increasing relevance of global satellite products for research, policy and management applications of satellite products places a high priority on providing users with rigorous and relevant accuracy information. A number of NASA, ESA and EU funded global and continental burned area products have been developed using coarse spatial resolution satellite data, and have the potential to become part of the long-term fire Essential Climate Variable record. The MODIS sensor on the AQUA and TERRA platforms provide the longest available record of reprocessed, science quality global satellite observations, specifically designed for global environmental monitoring. As the aging MODIS sensors, launched in 1999 and 2002 respectively, are nearing decommissioning, the VIIRS mission, started in 2012, is going to provide data continuity: the VIIRS VNP64A1 burned area product is therefore designed to replace the MCD64A1 MODIS product. In this paper, we present the preliminary results of the assessment of the consistency of the two products.

Methodology

The analysis involved two separate stages. As a preliminary step, the continuity of the most recent Collection 6.1 MCD64A1 and Collection 2 VNP64A1 burned area products is assessed by comparing the two monthly time series of burned area for the entire overlap period (2012-2023) at a variety of scales (from global to sub-continental). The validation against independent reference data is performed using the same dataset and methods developed for the Collection 6 MCD64A1 product. The design-based validation procedure adopts a tri-dimensional sampling grid that allows for probability sampling of Landsat data in time and in space. To sample the globe in the spatial domain with non-overlapping sampling units, the Thiessen Scene Area (TSA) tessellation of the Landsat WRS path/rows is used. The TSA grid is then combined with the 16-day Landsat acquisition calendar to provide tri-dimensonal elements (voxels). This allows the implementation of a sampling design where not only the location but also the time interval of the reference data is explicitly drawn by probability sampling. The adopted sampling design is a stratified random sampling, with two-level stratification of the voxels based on biomes and fire activity. This sampling approach was used for the selection of a reference dataset consisting of 558 Landsat 8 image pairs, visually interpreted according to the CEOS Burned Area Validation Protocol.

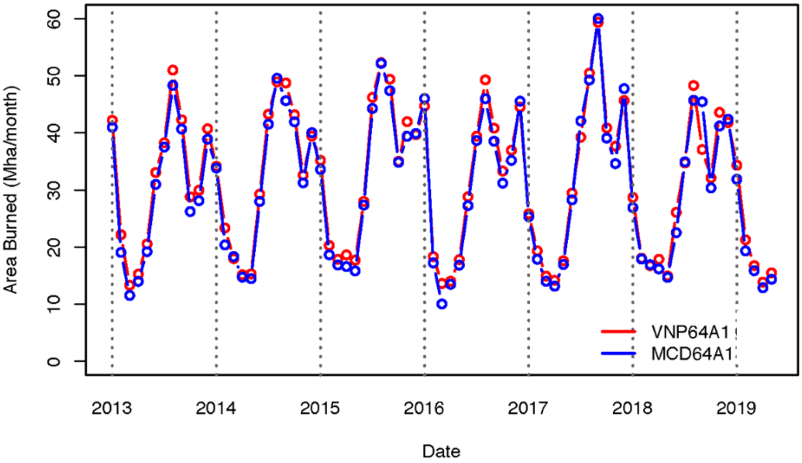
Expected results

The preliminary results of the time series analysis indicate that the two products define the same burned area trends and interannual variation, with minimal discrepancies that can be attributed mostly to sensor outages, and to different sensitivity to clouds as the VNP64A1 product is generated from a single sensor with afternoon overpass time, instead of morning and overpass time in the case of the MODIS products. The validation results against the Landsat reference data are reported in terms of product accuracy measures that are important for different types of fire users: (i) metrics derived from the confusion matrix (overall accuracy, omission error, commission error, relative bias), to assess pixel level mapping accuracy compared to 30m resolution data, (ii) area regression metrics, to assess the accuracy and precision of areal estimates over coarse resolution cells, to account for the compensation of omission and commission due solely to the low sensor resolution. The preliminary validation results indicate a substantially identical performance of the two products, with slightly higher VNP64A1 errors likely due to the lower resolution of the 750m reflectance data.

Outlook for the future

Our understanding of the global fire activity and its role in the Earth System has been informed primarily by coarse resolution global fire products and in particular by the NASA MODIS fire products. As the MODIS sensors are nearing their decommissioning, VIIRS will provide the necessary continuity. Our preliminary results indicate that the VNP64A1 burned area product has nearly identical accuracy compared to the MCD64A1 product, and that it defines the same temporal trends and interannual variability. Combined, the

MODIS and VIIRS fire products will provide the first ever global fire record covering the 30 years conventionally required for climate analysis, i.e. the duration of a time series used to generate “Climate Normals”.



Monthly time series of global area burned mapped by the VNP64A1 and by the MCD64A1 global burned area product, from 2013 to 2019.

Large Scale Assessment of Fire Impacts On Siberian Peatlands Carbon Through High-resolution Datasets

Amin Khairoun[1,*], Philippe Ciais[2], Thu-Hang Nguyen[2], Chunjing Qiu[3,4], Filipe Aires[5], Sander Veraverbeke[6], Clement J. F. Delcourt[6], Emilio Chuvieco[1]

1 *Universidad de Alcalà, Environmental Remote Sensing Research Group, Department of Geology, Geography and the Environment, Alcalà de Henares, Spain*
2 *Laboratoire des Sciences du Climat et de l'Environnement, LSCE/IPSL, France*
3 *Research Center for Global Change and Complex Ecosystems, School of Ecological and Environmental Sciences, East China Normal University, Shanghai, China*
4 *LERMA, Observatoire de Paris, Remote Sensing, Paris, France*
5 *ESTELLUS, Paris, France*
6 *Faculty of Science, Vrije Universiteit Amsterdam, Amsterdam, The Netherlands*

**Corresponding author:* amin.khairoun@uah.es

Keywords: burned area, peatlands, peat fires, carbon combustion, Landsat

Challenge

Peatlands are the world's largest natural terrestrial carbon sink. Arctic fires represent one of the major agents responsible of carbon released from permafrost. Coarse-resolution Burned Area (BA) datasets revealed that fire had largely affected carbon-rich peatlands in the Siberian arctic region. However, accurate evaluations of the impacts of these fires on peatland carbon stocks using high-resolution data are lacking. In this work, we present a wall-to-wall assessment of fire impacts over the entire Siberian region for the period 2001-2023 using new high-resolution maps of BA and peatland cover. We analyse peat fire trends over time and their impacts on belowground carbon stocks and the drivers of spatio-temporal variability. This assessment allows to redefine the importance of fire in peatland degradation at higher certainty.

Methodology

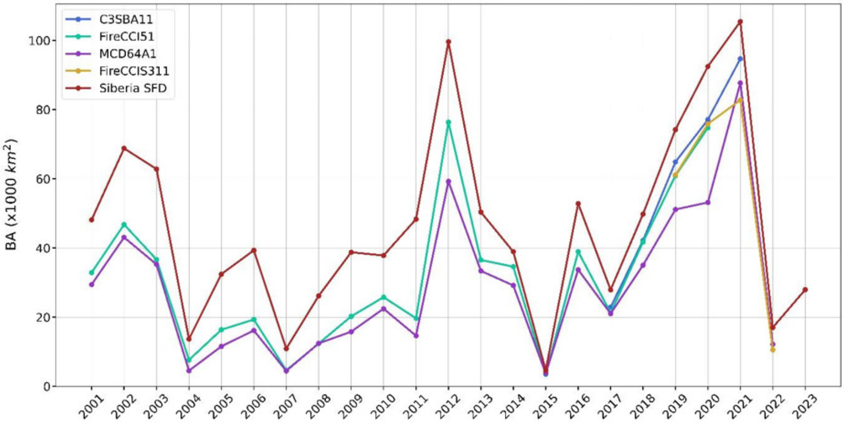
The BA mapping mainly relies on a semi-automatic approach based on a Random Forest model that ingests yearly mosaics of spectral indices (NBR, NBR2 and NDVI) and bands derived from Landsat imagery at 30 m along with visually collected training samples in Google Earth Engine platform. The mosaicking depends on the minimum NBR as it represents the day corresponding to the highest burning signal. Then, a growing region around seed pixels with high burning confidence is applied to derive BA patches. Afterwards, a two-step post-processing strategy is used to generate final BA maps. First, fire patches are smoothened using morphological operations. Then, active fires from MODIS and VIIRS sensors are used to reduce omissions caused by the lack of observations and to assign the most probable burning dates. Peatland maps are based on downscaling approaches that fuses several coarse-resolution hydrological and topographic datasets with Landsat imagery to predict probability of peatland occurrence at 90 m spatial resolution (3 Landsat pixels) then resampled to the resolution of BA maps to apply the overlay. Burning depth and carbon combustion due to fire are estimated by using a machine learning model that considers a wide range of predictors that are related to fire severity, climate conditions, topography and soil structure and composition.

Expected results

BA was mapped over the Siberian region expanding over around 9 Mkm2 (extent: 63E-180E; 60N-74N) for the period 2001-2023. The yearly BA predicted in this dataset shows a large variability as it ranges from 4,634 Km2 in the year of 2015 to 105,473 in 2021 with an average of 46,464 ± 26,811 Km2. A significant increase was observed in the years 2017-2021 perhaps due the dry conditions caused by the 2015-2016 El Niño–Southern Oscillation (ENSO). The comparison of our estimates (Siberia SFD) with Coarse-resolution BA products reveals the same trend. Our aim is to overlay fire information with peatland maps as a first step to assess the importance of fire a driver of permafrost degradation. Then, in each pixel of burned peat a model is designed to assess belowground carbon released to the atmosphere. This variable along with burning depth have been linked to several variables including fire characteristics as severe fires are expected to burn deeper and cause long periods of smouldering. On the other hand, climate conditions prior to fire might be highly associated with burning depth as dryness tend to drive water table deeper. The status of peat in terms of soil composition and structure generally affect carbon combustion rather than burning depth since different types of peatlands have different carbon content and/or density levels. Finally, lowlands tend to have a higher water table than uplands and therefore topography is considered an important factor in our modelling design.

Outlook for the future

The work presented in this abstract focuses mainly on the assessment of fire impacts on Siberian peatland carbon sink. We also intend to link the estimations of carbon combustions and their spatio-temporal trends with the driving agents (climate, land use change, etc.) to evaluate the main causes of these trends and variability. Our methodology could be generalized over the rest of boreal peatlands in Alaska and northwestern US territories as the modelling framework includes field data from this region as well. We intend to apply a sensitivity analysis to verify the robustness of the model estimation in different regions. In this way, a general evaluation of the entire arctic peatland fire emissions could be carried out and the patterns could be assessed in the different regions across the globe.



Trends of BA using the different coarse-resolution BA products against Siberia SFD.

Rapid UK Wildfire Mapping with Planet data

Akram Abdulla[1], Kevin Tansey[1,*]

1 University of Leicester, School of Geography, Geology & The Environment, UK

**Corresponding author:* kjt7@le.ac.uk

Keywords: earth observation, burned area, planet, small fires

Challenge

Wildfire has a significant and growing impact on the environment. The increasing prevalence and frequency of wildfires directly challenge our ambitions around enhancing habitat and the natural environment, and our ambitions around achieving net zero carbon status. Many organisations are working to develop and refine approaches to managing wildfire risk and responding to fires when they occur. Future climate change is predicted to significantly increase the risk of wildfire in the British Isles with severe summer fires being 3 to 4 times more likely by the 2080s. Between January and August 2022, the UK suffered a staggering 969 wildfires, compared to 247 in 2021. There is an urgent need for a more effective and rapid mobilisation of fire control and provision of information about the immediate post fire impacts to enable timely interventions to minimise secondary impacts such as sediment erosion and runoff of organic and inorganic pollution of water resources.

Methodology

Very high-resolution SEO with a high repeat cadence has offered the opportunity to monitor both the conditions leading to wildfire and the immediate impact of fires, enabling a rapid proactive response. However, access to the data and insight provided by such sensors and systems remains in the expert domain and is rarely available to influence operational decisions, but rather forms the basis of a posteriori analysis. To be operationally useful, large volumes of data require processing and analysis in near real time, data from a variety of sources both SEO and field observation collected automatically using IoT enabled environmental sensors, require integration allowing non-expert users direct insight into conditions and the information required for an immediate operational response. A further barrier is the skill and expertise required from the stakeholders to make decisions over which imagery should be selected, managing cloud or smoke haze, selecting the right spectral indices, geolocating the area of interest and manually undertaking these tasks on a day-to-day basis. Finally, dissemination of key information data sets to authorities, partners as spatial data layers or reports. The solution prototype will utilise Planet data (3-5m spatial resolution, at least and sometimes better than daily repeat) to continuously map regions being flagged detected as a wildfire in the UK to characterise the burned area development (spread) and burn severity (impact) information. Figure (a) shows the coverage of Planet data over a 5-day time window. Multiple observation solutions are noted. Planet data can provide at least daily observations of the land surface at 3-5m resolution. The workflow of the current service concept is shown below in Figure (b). Machine learning tools are utilised to train and then classify the burned area. A number of different training solutions are generated to take into account the differing mature of burned vegetation and the particular properties of fires in the UK which are often, but not always, associated with urban areas.

Expected results

Outputs are digital layers in raster and vector format of the perimeter of the fire and associated severity indicators. If cloud cover or smoke obscures the land surface, we will continue to map until a complete burned area map is acquired and the fire is extinguished. The mapping solution is offered via machine learning from a range of UK fire scenarios in the past. All of this processing is undertaken in the cloud and the results published to an open access geo-web server. An example of the burned area map result is shown in Figure (c). A total of 21 potential training sites have been identified. With the summer period coming up, we will test the ability to auto map burned areas by receiving alerts as to the spatial and temporal location of fires from active fire data or alerts from ground stations from a number of stakeholders whom we are working with (The UK's National Trust).

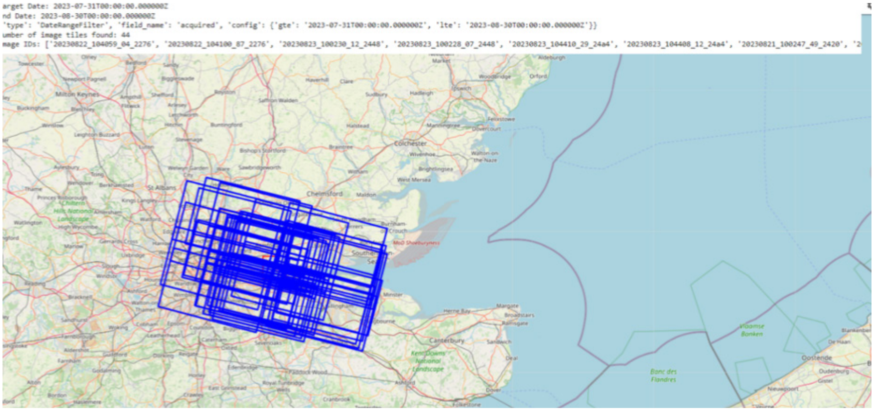
Outlook for the future

The research will be directed in a number of different ways in the future:

- expansion of the training and test area to European countries;
- dedicated user interface so results can be commissioned, generated and visualised by different users;

- archive data mode so that historic burned areas can be assessed;
- 24/7 mapping and production availability.

An accuracy assessment tool so that confidence in the accuracy of products can be provided to the users.



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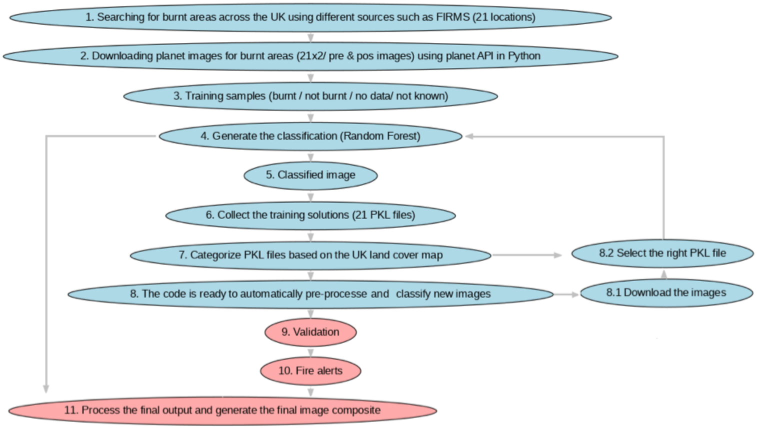
(a) Example of coverage provided by Planet data over a test site in the UK.



(b) Workflow.

(c) Results of a burned area map (green is the outline of the burned area; red indicates some islands of unburned in the scene).

The Forest Fire Danger Prediction System of México

Daniel José Vega Nieva[1,*], Jaime Briseño Reyes[1], Carlos Briones Herrera[1], Adrián Silva Cardoza[1], José Javier Corral [1], Pablito Marcelo López Serrano[2], Eduardo Cruz Castañeda[3], César Alberto Robles Gutiérrez[3], Yair Ricardez[3], Juan Miguel Campos Muñoz[3], Fabiola Esquerra[3], Alicia Verónica Salas[3], Ursula Berenice García Herrera[3], María Isabel Cruz López[4], Martín Cuahutle Cuahutle[4], Rainer Ressl[4], William Matthew Jolly[5], Robert E. Burgan[5], Ernesto Alvarado[6], Sean A. Parks[7], Lisa M. Holsinger[7]

1 *Facultad de Ciencias Forestales, Universidad Juárez del Estado de Durango, Durango, México*
2 *Instituto de Silvicultura e Industria de la Madera, Universidad Juárez del Estado de Durango, Durango, México*
3 *Comisión Nacional Forestal (CONAFOR), Zapopan, Jalisco, México, Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), Ciudad de México, México*
5 *Rocky Mountain Research Station, USDA Forest Service, Missoula, MT 59802, USA*
6 *School of Environmental and Forest Sciences, University of Washington, USA*
7 *USDA Forest Service, Aldo Leopold Wilderness Research Institute, Rocky Mountain Research Station, Missoula, USA*

**Corresponding author:* danieljvn@gmail.com

Keywords: fire danger, fire risk, fire hazard, active fires, fire intensity

Challenge

The Forest Fire Danger Prediction System of México (SPPIF) is an operational decision-support tool for forest fire management in México. Maps are updated daily from weather, active fire and fire suppression information. It allows to monitor near-real time fuel greenness and associated fire risk and danger to support decision making in fire management. In particular, it offers information about fuel dryness, expected number and location of fire events and burned area, and expected fire intensity (MW/km2). The maps allow to support decision making for fire detection planning, suppression prioritization, optimizing number and location of fire suppression resources, allowing to assign most appropriate fire suppression resources to each fire and to orient prescribed and agricultural burn timing, fire management plans and to aid in planning fuel treatment and long-term strategic fire prevention, suppression and restoration resources allocation. It is publically available online at: http://forestales.ujed.mx/incendios

Methodology

SPPIF includes the following sections: 1) daily fire suppression registers from CONAFOR, 2) near-real time active fire perimeters and fire intensity, 3) fire danger indices, including: Fuel dryness index (FDI). FDI is an adaptation by Vega-Nieva et al. (2018, 2019) of the FPI index (Burgan et al., 1998) based on daily weather and MODIS-based fuel greenness information supplied daily by CONABIO and the Mexican National Weather Service (SMN-CONAGUA).

Expected active fire density (ignition risk) and forest fire density (forest fire occurrence risk). Expected density of active fires by fuel type and region is calculated daily from the FDI and the observed active fires from the previous days (Vega-Nieva et al., 2018, 2021). The fire ignition density index is combined with a human fire occurrence risk map, considering historical fire suppressions (Monjarás-Vega et al., 2020), to forecast expected daily forest fire density. Expected fire intensity. Daily forecasts of expected VIIRS FRP density (MW/km2) are produced based on statistical models calibrated with 10 years of active fires, considering weather (fuel dryness and wind), fuel availability, and previous FRP density. Expected number of fires and burned area by state. Based on forecasted fuel moisture and observed number of fires and burned area from the previous days, autoregressive forecasts (Vega-Nieva et al., 2024) of expected number of fires and burned area are produced for the next 10 days for every state of México.

Expected results

SPPIF allows to monitor the observed and forecasted number of active fire clusters by state (Figure 1 a), and to visualize a dynamic count of active fire perimeters (Figure 1 b). The near real-time active fire perimeters (Briones-Herrera et al., 2020, 2022) allow for preliminary burned area assessment (Figure 1c). and to monitor daily fire spread (Figure 1d). Examples of daily fire danger indices to support fire management in México are shown in Figure 2 (a-c). The monitoring of expected fire intensity (Figure 2d) and observed fire intensity (Figure 2d and 2e) allows to prioritize fire suppression resources based on expected behaviour. In addition, tools for mapping burned are and severity (Figure 4e) from Sentinel (Briones-Herrera et al., 2023), validated with field information from 700 field plots of burn severity (e.g. Silva-Cardoza et al., 2021, 2022) are available in SPPIF.

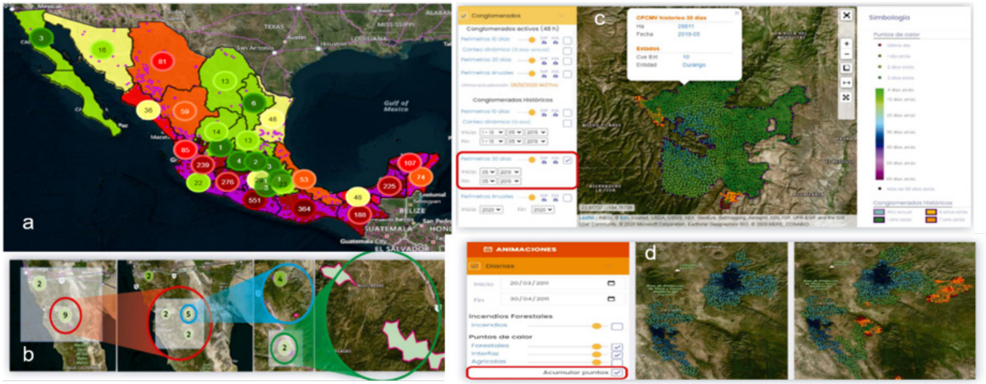


Figure 1. Observed and Forecasted Number of active fire perimeters (10/05/2022) (a); dynamic count of active fire perimeters in Baja California (b); active fire perimeter in Durango, 2019 (c); daily animation of fire spread (d).

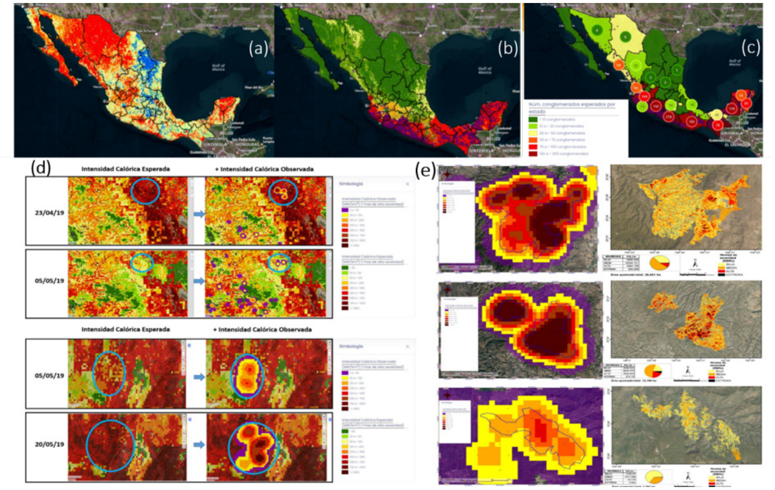


Figure 2. (a) Fuel Dryness Index; (b) Ignition Risk and observed active fire perimeters; (c) Expected and observed number of fires by state; (d) Expected and observed active fire intensity for 2 selected fires and (e) details of observed fire intensity -VIIRS FRP density (MW/km2)- shown in SPPIF (left) and Sentinel burn severity (right) for 3 selected fires in NW México.

Outlook for the future

Future developments for the Forest Fire Danger Prediction System of México, in the frame of ongoing research projects funded by World Bank and USFS-NORTHCOM, include:

- to update SPPIF fuel moisture indices using GOES, VIIRS and NOAA weather forecasts for México;
- to include the visualization of NOAA smoke forecasts and GOES active fires in SPPIF;
- to include the quantification of emissions from GOES and VIIRS FRP in SPPIF;
- to validate tools for mapping burned area and burn severity with field and UAV data;
- to enhance fuel mapping using UAV and GEDI and to integrate those fuel maps into fire intensity forecasts.

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Data-Driven Wildfire Spread Modelling of European Wildfires

Moritz Rösch[1,*], Michael Nolde[1], Torsten Riedlinger[1]

1 German Aerospace Center (DLR), German Remote Sensing Data Center (DFD), Germany

**Corresponding author:* moritz.roesch@gmx.de

Keywords: wildfire spread modelling, deep learning, remote sensing time series, graph-based modelling, Mediterranean

Challenge

Human-induced climate change is causing wildfires to intensify and become more frequent acro ss the globe, as evidenced by recent extreme events in Greece (2023), Canada (2023), and Chile (2024). To effectively manage these risks, wildfire spread models play a crucial role in planning timely suppression efforts. Historically, wildfire spread models have been developed using semi-empirical approximations based on experimental burnings. Although used in an operational context, such models suffer from inaccuracies and transferability issues outside of their development region. Recent advances in the availability of remote sensing data, artificial intelligence, and computational resources allow for a new data-driven perspective on wildfire spread modelling that offers the opportunity to overcome the limitations of established semi-empirical models.

Methodology

We developed a novel data-driven wildfire spread modelling approach using a Spatio-Temporal Graph Neural Network (STGNN) trained on the historic burned area time series of European wildfires retrieved from Copernicus Sentinel-3 imagery. A training dataset was built by populating individual burned area perimeters with dynamic (e.g. meteorological data, Fire Weather Index (FWI), hotspots) and static (e.g. fuel map, land cover, topography) auxiliary datasets in a discrete, hexagonal grid system (H3), which allows to include neighbourhood relationships into the dataset. Each wildfire time series was then transformed into a spatio-temporal graph representation which formed the input for the model. The STGNN can simultaneously process and learn the spatial and temporal dependencies in the data by combining a Graph Convolutional Network (GCN) with a Gated Recurrent Unit (GRU). The model was iteratively trained on each time step of individual wildfire time series and can predict the next day's burned area. Testing was done by feeding the first day of an unseen wildfire time series and predicting the wildfire's burned area on the four following days. Validation was achieved by calculating the weighted macro-mean Jaccard Index (IoU) between the predicted daily burned area and the Sentinel3 reference burned area. A first model was developed on Portuguese wildfires to test the ability of the STGNN to capture the spatial and temporal evolution of wildfires. To assess the generalization ability of the wildfire spread model, the STGNN was then trained and tested with Mediterranean wildfire time series from different countries with varying environmental conditions.

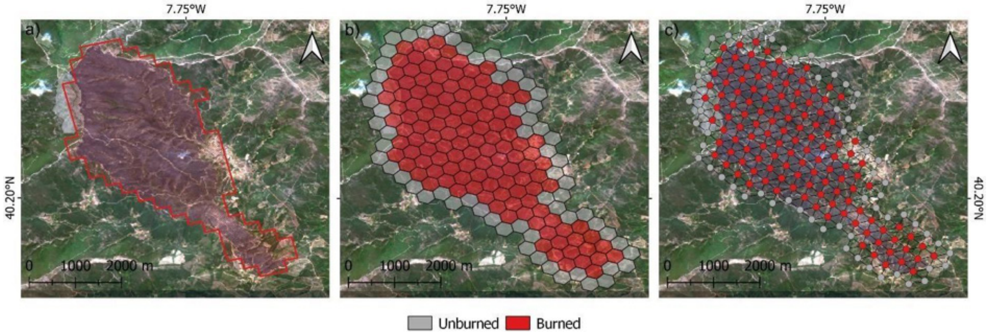
Expected results

Both the Portugal and Mediterranean models were able to predict the next day's wildfire spread with an overall weighted macro-mean IoU of 0.37 and 0.36, subsequently. Both models could capture the general temporal trend of a wildfire but suffered from an overprediction bias. A robust performance was achieved across all fire seasons from 2017 to 2022, indicating that the extent of a fire season does not significantly affect the results. The results show an increase in IoU values with an increasing fire spread size up to an optimum of approx. 5 km2. The lowest accuracies were achieved on days without any fire spread, which occur frequently in the reference dataset, explaining the overall moderate performance metrics resulting from the overprediction bias. The prediction performance of both models increased with ongoing prediction days, resulting in the highest IoU values on the last day of the testing time series. The Mediterranean model was able to generalize well over varying environmental conditions and fire regimes in different countries. Wildfires in Spain were predicted most accurately with an overall weighted macro mean IoU of 0.44, closely followed by Greece (0.43), and Portugal (0.39). These countries also experienced the largest and most intense wildfires in Europe. Countries with smaller and less intense wildfires (e.g. Italy) were predicted with lower accuracies (IoU < 0.34).

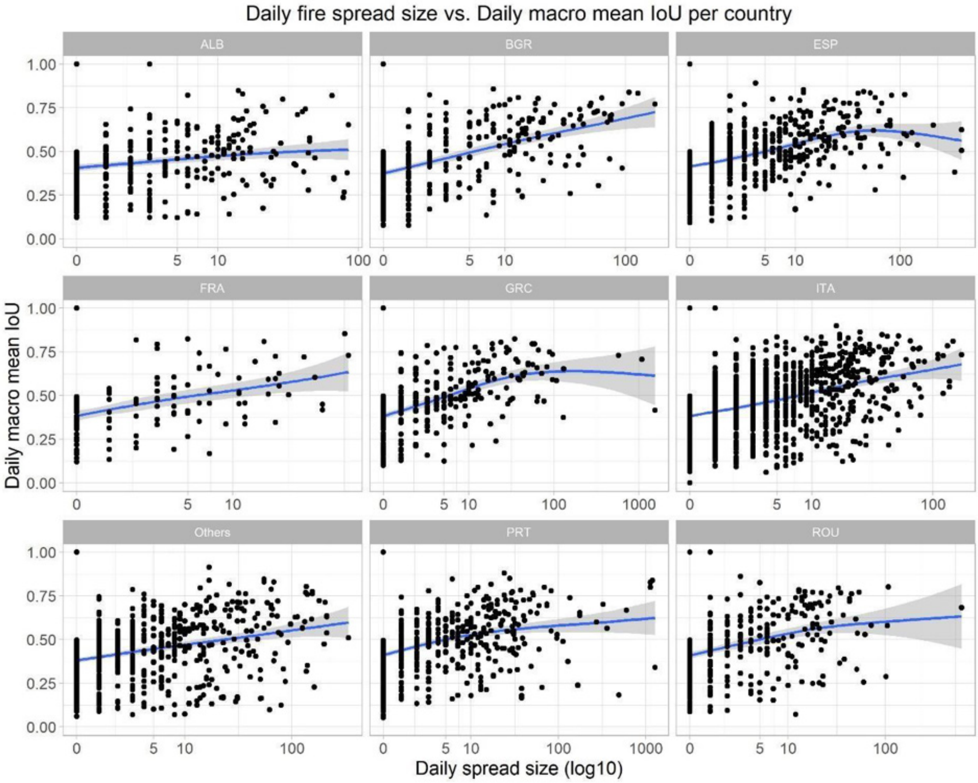
Outlook for the future

This work demonstrated a novel, data-driven approach to model wildfire spread based on historical burned area time series and environmental variables. Our results show that the spatial and temporal dimensions of a wildfire greatly influence the model performance.

This supports the usage of a spatiotemporal graph-based modelling framework. Overall, the statistical evaluation showed only mediocre results in predicting the next day's wildfire spread but are in line with similar studies highlighting the complexity of this modelling domain. This lack of accuracy probably results from insufficient reference data quality. While not intended as a replacement for conventional semi-empirical wildfire spread models, a data-driven approach showed a promising way forward to potentially overcome the prevailing transferability issues. Therefore, the focus of future work should be on improving the reference data basis by creating datasets describing individual wildfire fire events with an improved temporal and spatial resolution.



Different data representations of the burned area on the 07.08.2020 of a wildfire in Portugal. Background: Sentinel-2 RGB image from the 07.08.2020. (a) Burned area perimeter as derived from Sentinel-3. (b) Burned area perimeter displayed in H3 cells. (c) Burned area perimeter displayed as graph structure.



Daily macro mean IoU of the Mediterranean model per country and daily spread size. The daily wildfire spread is defined as the number of new burned H3 cells (one H3 cell equals approx. 0.1 km²).

Monitoring Wildfires from Copernicus Sentinels and Integration in the CAMS Service

Dominika Leskow-Czyżewska[1], Stephan Bojinski[1], Julien Chimot[1], Andrea Meraner[1], Mark Parrington[2], and Federico Fierli[1,*]

1 EUMETSAT, Germany
2 ECMWF, UK

**Corresponding author:* federico.fierli@eumetsat.int

Keywords: earth observation, Copernicus, smoke, pollutants, emissions

Challenge

Satellite-borne observations offer the possibility to monitor wildfires and their impact worldwide. In addition, satellite products are increasingly used in early warning and forecasting systems for fire management. Europe is implementing a long-term and reliable observational programme and, within this frame, EUMETSAT, the European meteorological satellite operator, provides numerous observational products ranging from near-real-time wildfire identification (e.g. fire radiative power) to atmospheric impacts (e.g. major pollutants and smoke).

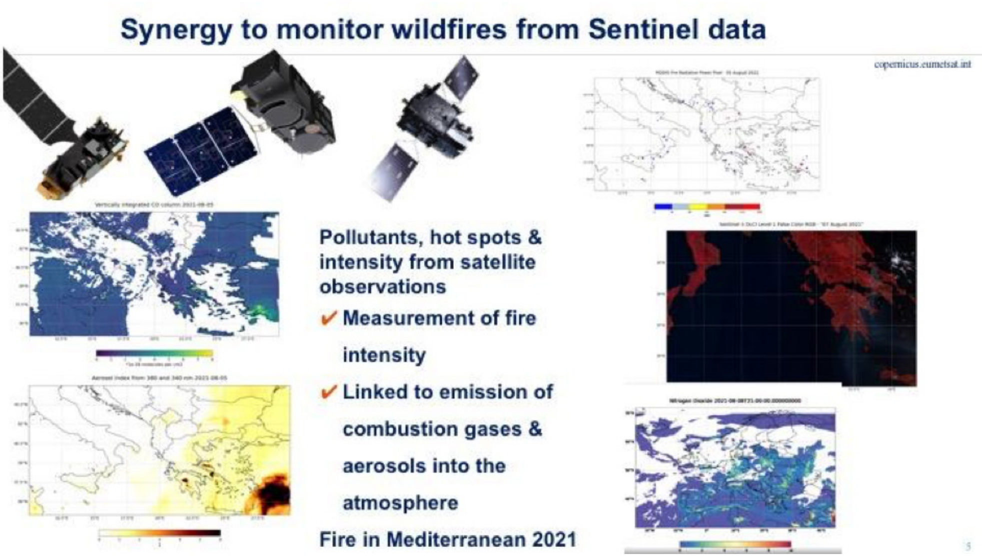
Methodology

Our presentation will focus on the satellite data value chain, e.g. the integration in the Copernicus Atmosphere Monitoring Service (CAMS) Global Fire Assimilation System (GFAS). To do that, we will firstly present datasets addressing wildfires (e.g. Fire Radiative Power, atmospheric composition, and smoke) currently generated at EUMETSAT and its Satellite Applications Facility (SAF). We will also introduce upcoming (based on the Flexible Combined Imager on-board the Meteosat Third Generation) and future products (Sentinel-4 and 5), with an example of potential joint use for a past intense fire case in the Mediterranean (Greece, August 2023).

Expected results

We show the entire value chain, including how the data is used in the Copernicus Atmosphere Monitoring Service (CAMS) Global Fire Assimilation System (GFAS), with an example on the recent intense and anomalous fire season in Canada (spring to summer

2023). This will show how distinct phases of wildfires management – from early warnings up to the impacts on yearly emissions – can be monitored with the synergy of satellite data and Copernicus forecast and analysis. Finally, we will touch also on the user support activities within EUMETSAT in this area.



Synergy to monitor wildfires from Sentinel data

copernicus.eumetsat.int

Pollutants, hot spots & intensity from satellite observations

- ✔ **Measurement of fire intensity**
- ✔ **Linked to emission of combustion gases & aerosols into the atmosphere**

Fire in Mediterranean 2021

From top right: FRP from SLSTR Sentinel-3, Visible corrected from OLCI Sentinel-3, Simulation of NO2 from Sentinel-4 UVN, CO from TROPOMI, Sentinel-5P, Aerosol Index from TROPOMI for the day August 2nd 2021.

Fire monitoring in Europe: the role of the European Forest Fire Information System (EFFIS)

Duarte Oom[1,*], Jesús San-Miguel-Ayanz[1], Alfredo Branco[1], Pieralberto Maianti[2], Roberto Boca[2], Daniele de RIgo[2], Davide Ferrari[3], Tracy Durrant[3], Elena Roglia[2], Nicola Scionti[2], Maria Suarez-Moreno[2], Marco Broglia[1]

1 European Commission, Joint Research Centre (JRC), Ispra (VA), Italy
2 External consultant for the European Commission, ARCADIA SIT s.r.l., Vigevano (PV), Italy
3 External consultant for the European Commission (Engineering Ingegneria Informatica S.p.A.) Rome, Italy

**Corresponding author:* duarte.oom@ec.europa.eu

Keywords: EFFIS, forest fires, forest monitoring, EU policy

Challenge

Wildfires are common in Europe, especially in the Mediterranean area. The European Union recognized the need for standardized and accurate data for EU policies. In 1998, the European Commission established the European Expert Group on Forest Fires (EGFF) composed for wildfire managers in the EU countries to exchange best practices and create the European Forest Fire Information System (EFFIS). Following the EC policies regarding fires (2158/92 and 2152/03), EFFIS started in 2000, covering the EU Mediterranean region using satellite sources such as Russian (MSU-E) imagery, Indian (IRS WiFS), and eventually MODIS imagery from 2003. Since 2018, EFFIS uses Sentinel-imager for detailed mapping. In 2015, EFFIS was included in the Copernicus Emergency Management Services. EFFIS has evolved since its establishment in 2002 along with the evolution of satellite sensors in the period. The following sections describe the current state of mapping active fires and burnt areas in EFFIS and its future developments.

Methodology

EFFIS utilizes the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor from NASA's Terra and Aqua satellites to consistently update the total burnt area in Europe since 2003. Before 2003, MSU-E and IRS WiFS were used. The sensor captures surface reflectance for the Red and Near-Infrared bands with a spatial resolution of 250 meters and for five bands with a spatial resolution of 500 meters. This data is used to map burnt areas, allowing for detailed mapping of fires of around 30 hectares or larger.

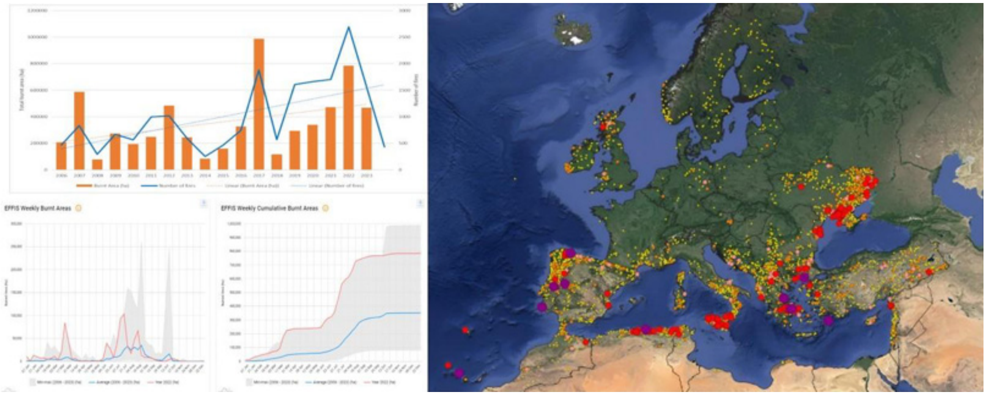
Historical fire data analysis shows that fires above 30 hectares account for about 85% of the total area burnt annually in the Southern EU. The cartography was updated twice a day in 2006 and three times a day since 2016. In 2018, the methodology was enhanced using the Atmospherically corrected Surface Reflectance bands from the SENTINEL-2 MultiSpectral Instrument (MSI) Level 2-A imagery, at a 20-meter spatial resolution, enabling the mapping of fires of about 1 hectare or larger. EFFIS uses data from the European CORINE Land Cover database to obtain the statistics of burnt areas by land cover type. Prescribed fires for management or conservation purposes are included, while non-wildland fires like agricultural or urban fires are excluded from the statistics. Information on each affected land cover type is provided. However, national statistics may not correspond with EFFIS figures if those consider only areas burned in forest areas. The EFFIS website offers continuously updated information on the ongoing fire season, daily meteorological fire danger maps, forecasts of fire danger up to 9 days in advance, updated maps of the latest active fires, wildfire perimeters, and post-fire damage evaluation.

Expected results

Between 2006 and 2023, EFFIS mapped around 60 thousand fires within its Area of Interest (AOI), including 19 thousand fires larger than 30 hectares. This accounted for a total area of 12 million hectares (with approximately 6 million hectares in fires larger than 30 hectares) which is roughly twice the size of Lithuania. Except for 2007, the worst five years in terms of total burnt surface were recorded in the last 7 years, with 2017 (988,427 ha), 2022 (837,212 ha), 2023 (504,002 ha), and 2021 (470,995 ha) being particularly severe. In Europe, the fire season typically begins with some fires in February and March, constituting approximately 13% of the total recorded in the year, but the wildfire activity peaks in the summer months from June to September, especially in the Mediterranean region, accounting for approximately 72% of the total fires. Since 2003, the ten largest fires recorded by EFFIS occurred in Greece (2023, 2021, 2007) and Portugal (2017, 2003). The year 2023 marked the occurrence of the largest single fire in Europe since the 1980s, igniting near Alexandroupoli, Greece, resulting in a burnt area of over 96,000 hectares and causing significant human casualties. These severe wildfire events are linked to extremely high fire danger conditions due to climate change. Analysis of vegetation types affected by the fires revealed that approximately 29% of the total burnt area was covered by shrubs and sclerophyllous vegetation, while 14% was forested. The wildfires caused severe environmental damage, resulting in an estimated 394 megatonnes (Mt) of CO2 emissions from 2006 to 2023, equivalent to 8% of the CO2 emissions from wildfires in Canada during the same period.

Outlook for the future

As mentioned above, EFFIS has continuously evolved since its conception and first operation in 2000. This evolution has gone hand in hand with the evolution of satellite sensors and information technology. As new satellites were launched during the 24 years of operation of EFFIS, new sensors provided additional and better earth observation data that helped in more precise and accurate mapping of wildfires and burnt areas. As wildfires are predicted to worsen in the coming years and decades especially in a climate change context (more frequent, larger, severe and intense), with high impacts over the population and environment, EFFIS and fire monitoring under the European Commission is likely to be shaped by the need to face those challenges. In that sense, EFFIS will evolve through the incorporation of new satellite sensors that can provide a more timely and accurate information on wildfire ignitions, propagation and damage. Among these, in addition to newer and better geosynchronous satellites such as VIIRS and Sentinels, geostationary satellites may play a key role. As their spatial resolution increases and false wildfire detection alarms are reduced, these sensors can provide a unique high-frequency spatial information of fire progression and intensity.



Graphical abstract.

Project SERAFIM – A Constellation of Nanosatellites for Rapid Active Fire Detection and Burnt Area Mapping

Max Bereczky[1,*], Dmitry Rashkovetsky[1], Michael Nolde[2], Torsten Riedlinger[2], Michael Schmitt[3]

1 OroraTech GmbH, Germany
2 German Aerospace Center, Earth Observation Center, Germany
3 University of the Bundeswehr Munich, Germany

**Corresponding author:* max.bereczky@ororatech.com

Keywords: earth observation, wildfires, hyperspectral, land use, copernicus

Challenge

Wildfires pose a global threat, exacerbated by climate change, leading to significant ecological and economic impacts. Traditional monitoring methods face limitations in timely detection and precise fire perimeter mapping, hindering firefighting and disaster management efforts. The SERAFIM Project, a cooperation between OroraTech GmbH, the German Aerospace Center and the University of the Bundeswehr Munich, addresses these challenges by developing an innovative satellite constellation aimed at enhancing wildfire detection and monitoring capabilities. Using advanced satellite technology and artificial intelligence (AI), the project seeks to overcome existing barriers in near-real-time fire detection by launching a constellation of 7 nanosatellites equipped with dedicated payloads specifically tailored for the cause.

Methodology

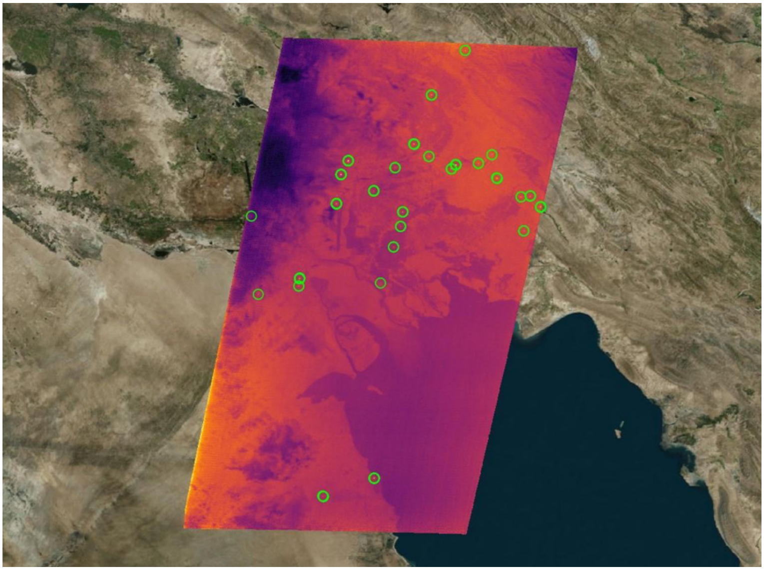
The SERAFIM project is actively engaged in exploring innovative methods across three key domains: Research in the field of burnt area and active fire mapping, on-orbit processing and georeferencing using artificial intelligence and the development of a constellation of nanosatellites tailored to wildfire detection and burnt area monitoring. To derive the most suitable spectral bands for burnt area mapping, a comprehensive evaluation based on hyperspectral data was conducted, indicating which spectral bands to incorporate into a purpose-built sensor for advanced burnt area mapping. To enable on-orbit georeferencing, machine learning models are being developed that perform land cover classification on long wave thermal data with the aim of spatially matching derived land cover features to existing reference land cover data in real-time onboard the satellite using a dedicated GPU. To allow detection of actively burning wildfires on-orbit, a fire detection algorithm was developed, deployed and tested on an operational precursor satellite mission in space. Furthermore, the serial production of a constellation of nanosatellites was established and the deployment of a plane of 7 satellites was prepared.

Expected results

The primary outcome of the project is the construction of 7 nano-satellites capable of performing nearreal-time, end-to-end detection and mapping of active fires and burnt areas in orbit. To achieve this outcome, we expect to identify and validate the minimum number of the most suitable spectral (infrared) bands that will allow achieving this goal. In addition, based on data from OroraTech's precursor mission FOREST-2, we expect to develop a fully automatic, AI-based georeferencing procedure for mid and long-wave infrared images. One of the primary expected scientific outcomes is the rigorous validation of ML algorithms' capacity to accurately detect and delineate active fires and burnt areas in various environmental conditions and terrains. Subject to variations in weather and data acquisition parameters, our objective is to demonstrate that active fires can be detected from orbit with a reliability that meets or surpasses the current benchmarks set by the state-of-the-art VIIRS sensor. Furthermore, a substantial amount of data regarding fire outlines and burn severity is expected to be collected. This data will play a pivotal role in analyzing the immediate effects of wildfires on ecosystems, as well as their longer-term ecological consequences. An additional expected outcome is the implementation of the ability to generate and disseminate alerts promptly following fire detection, aiming for near-real-time communication with ground-based emergency response teams.

Outlook for the future

We anticipate demonstrating that operational and reliable active fire detection can be achieved through the deployment of ML models in orbit. Furthermore, we expect to establish that a constellation of nanosatellites can provide reliable and prompt wildfire alerts in near-real-time. This advancement heralds a new era in environmental monitoring, disaster response, and climate change mitigation, showcasing the scalability and effectiveness of our constellation for precise wildfire detection. The SERAFIM Project's success promises not only immediate benefits for disaster management but also marks a significant stride towards long-term environmental protection and sustainability. Upon successful deployment of the initial constellation of 7 satellites, a potential direction for the project's next phase includes the exploration of on-orbit detection of burnt areas. This development would be contingent upon integrating a shortwave-infrared channel into the satellite's onboard detector.



Example of on-orbit detection of gas flares in Iran and Iraq. Detected gas flares are marked by green markers. Background image: FOREST-2 acquisition from 14.02.2024, 3.8 µm.

A Glimpse into the Potential Impact of Meteosat Third Generation's Flexible Combined Imager on Wildfire Detection from Satellites

Valerio Pampanoni[1,*], **Giovanni Laneve**[1]

1Sapienza University of Rome, School of Aerospace Engineering, Italy

**Corresponding author:* valerio.pampanoni@uniroma1.it

Keywords: earth observation, active fires, wildfire detection, hotspots, MTG, FCI

Challenge

The Flexible Combined Imager (FCI) is one of the payloads of the new Meteosat Third Generation (MTG) satellite, which will observe the full Earth disc in 16 spectral channels at nominal Spatial Sampling Distances (SSDs) of 1 and 2 km, and in 4 spectral channels at SSDs of 1 km (IR 3.8, IR 10.5) and 500 m (VIS 0.6, NIR 2.2) every 10 minutes. In addition, the Rapid Scanning Service (RSS) will provide the same observations every 2.5 minutes for the northern quarter of the disc. In particular, the IR channels involved in hotspot detection will match the resolution of the corresponding channels of instruments hosted on Low Earth Orbiting (LEO) satellites, such as MODIS (B20 and B31, 1 km), VIIRS (M12 and M15, 750 m), and Sentinel-3 (S7 and S8 1 km). This has the potential to revolutionise the field of active fire detection from satellites, enabling semi-continuous monitoring of wildfires from a geostationary (GEO) platform at a spatial scale which had always been confined to LEO satellites.

Methodology

In preparation for the operational distribution of the MTG products through EUMETCast, our aim is to assess the potentialities of the FCI products for hotspot detection in relation to existing LEO active fire products. To this end, we will compare the results of our wildfire detection algorithm SFIDE (Satellite FIre DEtection) with the hotspots detected by the FIRMS and EFFIS systems during the acquisition window of the test product disseminated by EUMETSAT. The SFIDE algorithm was originally designed to exploit the high refresh rate of the GEO sensor Spinning Enhanced Visible and Infrared Imager (SEVIRI) (Di Biase et al. 2018), aiming to maximise the detection sensitivity in order to counteract the coarse SSD of the sensor (~3 km). The method employs both the classical contextual approach and a novel change-detection approach enabled by the repeated observations provided by the GEO platform. The drawback of the method is the relatively high rate of false alarms, which was mitigated by introducing ancillary information such as: 1) comparing the current observations with the ones acquired at the same time of the previous days, 2) and with the previous two acquisitions; 3) introducing appropriate thresholds on the minimum Fire Radiative Power (FRP) value. In this case, the raw netCDF products provided by EUMETSAT were extracted and pre-processed in Python by making use of the already available functions in the h5py and satpy libraries.

Expected results

We aim to adapt the SFIDE algorithm to exploit the higher SSD of the MTG platform, with a particular focus on the (High spatial Resolution Fast Imagery) HRFI product, which contains the observations at 1 km and 500 m resolution. Since the test dataset contains a single full disc observation, we will not be able to apply the change-detection portion of the SFIDE algorithm. Therefore, we will only adapt the components of SFIDE that can be applied to a single observation:

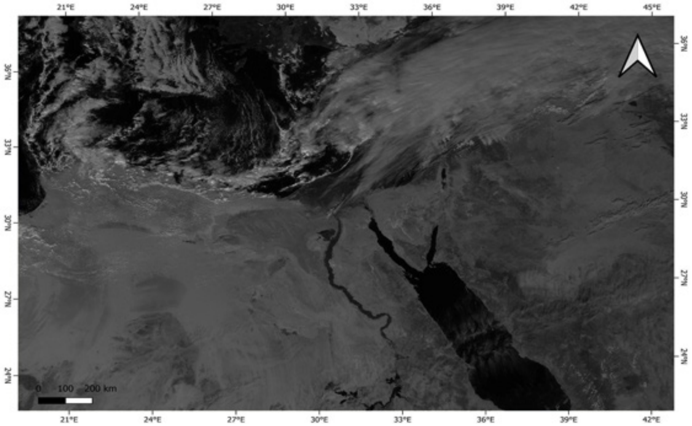
- HRFI image pre-processing;
- Calibration of the radiance products to reflectance or Brightness Temperature (BT);
- Cloud masking using the VIS_06 channel;
- Application of a fixed threshold to the IR_38 channel;
- Application of a fixed threshold to the difference in BT between the IR_38 and IR_105 channels;
- Hotspot confirmation through contextual analysis;
- Hotspot characterization (FRP).

This will provide a 1 km resolution active fire mask and FRP map based on the Wooster approximation (Wooster et al, 2005).

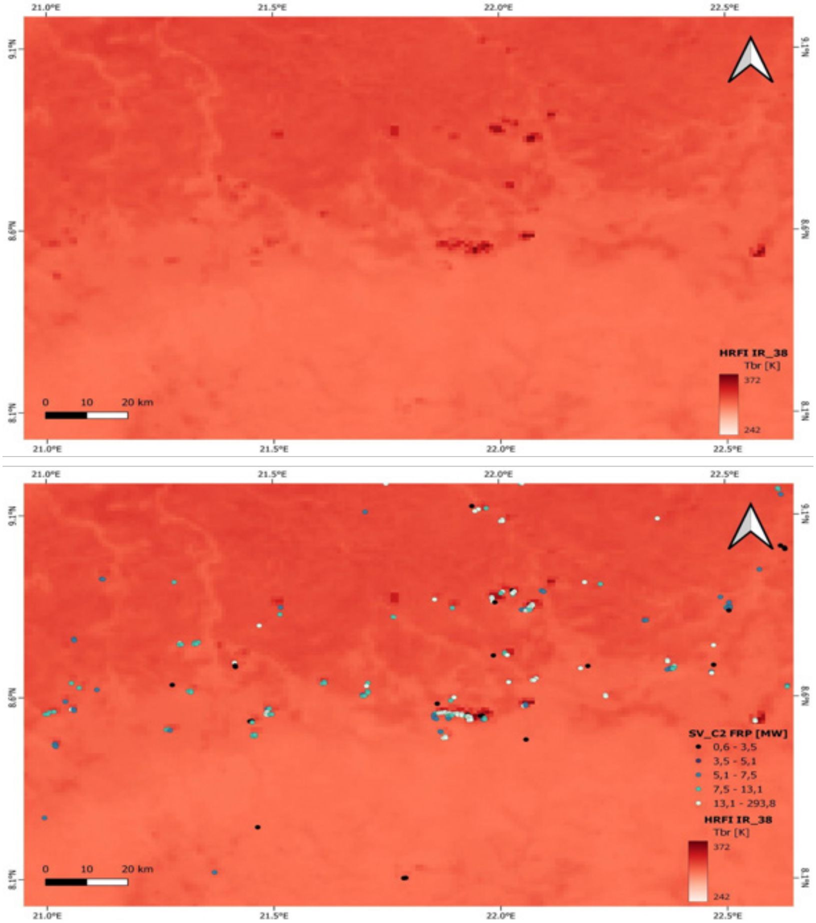
An active fire product based on HRFI imagery is expected to perform similarly to equivalent products associated with LEO platforms such as FIRMS Active Fire products (MODIS, VIIRS etc) and EFFIS hotspots (SLSTR). In terms of absolute sensitivity, quantified by the minimum FRP which can reliably be resolved, LEO active fire products are still expected to slightly outperform HRFI hotspots, since 1) their pixel size on the ground will be equal or better than MTG, and 2) their algorithms are greatly developed and time-tested.

Outlook for the future

Adapting SFIDE to MTG will allow us to glimpse into the potentialities of the MTG FCI for the future of hotspot detection from GEO satellites. However, since the test dataset contains only a single full-disc acquisition, the real potential of the platform for hotspot detection will be exploited when the data dissemination will be operational, and we will effectively be able to make use of the semi-continuous observations allowed by the GEO platform. This will allow monitoring the behaviour of wildfires and their FRP progression at an unprecedented temporal scale, which in turn may greatly affect our current knowledge of fire behaviour modelling. On the operational side, reliable early detection of smaller than ever fires for the full Earth disc observed by MTG may greatly affect our capability to respond to wildfires on the ground, both in terms of reaction time and in terms of firefighting strategy. Nevertheless, these early efforts will enable useful improvements not only for what concerns the hotspot detection algorithm, but also for the MTG image pre-processing, with a particular focus on more precise georeferencing and cloud masking.



Zoom-in of the 500-meter resolution MTG HRFI VIS_06 Channel (reflectance) over the Nile Delta region. The observation was acquired between 11:50:07 and 11:59:24 UTC of the 13th of January 2024.



Zoom-in of the 1 km resolution MTG HRFI test dataset IR_38 Channel (brightness temperature) over the Parc National du Manovo-Gounda-Saint Floris, Central African Republic (top), with overlaid VIIRS hotspots (bottom). The MTG observation was acquired between 11:50:07 and 11:59:24 UTC of the 13th of January 2024, while the VIIRS hotspots were detected at 11:38 UTC. Many can easily be spotted as dark red pixels even by the untrained eye.

Posters

Deep Learning Approach for Spectral Unmixing of PRISMA Data in Wildfire Scenario

Andrea Carbone[1,*], Stefania Amici[2], Dario Spiller[1], Giovanni Laneve[1]

1 *Sapienza University of Rome, School of Aerospace Engineering, Rome, Italy*
2 *National Institute of Geophysics and Volcanology (INGV), Rome, Italy*

[*] *Corresponding author:* and.carbone@uniroma1.it

Keywords: spectral unmixing, data mining, deep learning, fire Scenario, PRISMA

Challenge

This study is based on wildfire data from Australia and Oregon, acquired by PRISMA, an Italian satellite providing hyperspectral imagery. Previous research has highlighted the efficacy of Convolutional Neural Networks (CNNs) in wildfire analysis and detection (Carbone et al., IEEE MetroXRAINEE, 2023). However, besides detecting fires, understanding the concentration of each class involved in the fire-affected area is crucial. In a PRISMA image with a spatial resolution of 30 meters, multiple classes may coexist in each pixel. Identifying these classes and their concentrations provides crucial information about the spread and extent of fires. This work explores the potential of CNNs for assessing spectral pixel unmixing, as opposed to traditional methods like the look-up table approach, which can be resource-intensive in terms of required storage memory. For example, with five classes each ranging from 0% to 100% with a step of 10%, there are 161051 possible combinations, requiring GBs of storage. In contrast, CNNs have a memory impact of just a few MB, while maintaining the same level of accuracy.

Methodology

The dataset used to train the CNN is derived from that employed in the previously cited work. It consists of the spectral signatures of PRISMA images from two forest fires: one in New South Wales, Australia, on December 27, 2019, and another in the Fremont-Winema National Forest, Oregon, USA, on July 17, 2021. Within this dataset, ten signals are carefully chosen for each class through visual spectrum inspection. These signals are selected to best represent the pure characteristics of each class, closely resembling spectra containing 100% of each respective class. To enrich the dataset, the mean and standard deviation of the ten manually selected pure signals for each class are evaluated. Leveraging this statistical information, 100 random signals are generated around the mean signal, employing a Gaussian distribution. This augmentation approach effectively expands the dataset of pure pixels for each class, enhancing its diversity and robustness, while also enabling the repetition of the dataset creation process, resulting in the generation of distinct random pure signals each time. Subsequently, all possible linear combinations of pure signals are evaluated, resulting in a dataset comprising 100,000 mixed signals, each accompanied by its respective percentage compositions. The resultant dataset is then partitioned, with 20% allocated for testing and 80% for training the neural network. Notably, within this 80%, 15% is reserved for the validation dataset.

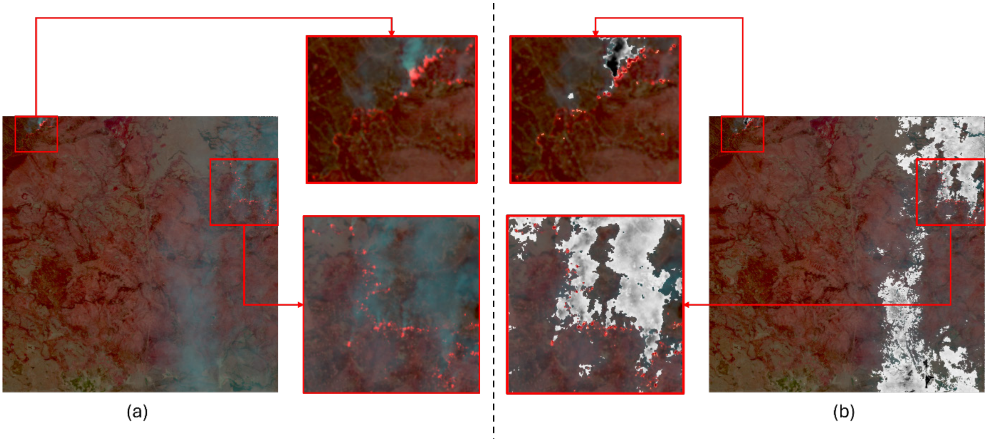
Results

Outcomes of this study include a notable enhancement in wildfire analysis and detection accuracy compared to conventional methods. Utilizing CNNs for spectral unmixing is expected to enable precise identification and characterization of diverse land cover classes within wildfire-affected regions. This refined understanding of class concentrations in PRISMA imagery, facilitated by CNN-based spectral unmixing, promises valuable insights into fire spread and extent. Additionally, CNNs are projected to demonstrate superior memory efficiency, minimizing storage requirements compared to traditional approaches such as look-up tables. The preliminary results obtained from the 1D-CNN-based spectral unmixing technique are noteworthy, especially in distinguishing between ‘Fire’ and ‘Smoke’ classes (refer to Figure). These results demonstrate remarkable accuracy at 0.99, with the mean square error impressively low at 10^{-4}, indicative of the model’s precision. Equally impressive is the rapid inference time clocking in at 8.72×10^{-5} seconds, underscoring the efficiency of the approach. Overall, these expected results suggest that CNN-based spectral unmixing holds considerable promise for advancing wildfire analysis and detection, offering a more accurate, efficient, and resource-effective approach to evaluating wildfire impacts.

Outlook for the future

In our upcoming research, we plan to utilize Sentinel images to validate the proposed CNN-based spectrum unmixing. We will leverage Sentinel data to conduct discrete fire class classification, resulting in a grid of classified pixels with a resolution of 10 meters.

Subsequently, the spectral unmixing grid from PRISMA will be overlaid onto the one obtained from Sentinel. This process will enable us to acquire, for each pixel from PRISMA, 9 corresponding pixels from the Sentinel classification. Essentially, this will furnish us with data on the percentages of each class within each pixel of the spectral scrambling grid. For instance, if a PRISMA pixel indicates 50 percent burned area and 50 percent vegetation, and the corresponding 9 pixels in the Sentinel classification reveal 5 as burned area and 4 as vegetation, we can assess the accuracy of PRISMA's land cover assessments. This technique will furnish a robust tool to validate the results, which already exhibit considerable promise from preliminary analyses.



(A) A false-color image of Oregon captured by PRISMA, where the red, green, and blue channels are selected as the means of bands between 2300-2400 nm, 520-580 nm, and 450-500 nm, respectively. (B) False-color image with "Fire" and "Smoke" classes predicted by 1D-CNN, visually represented in scales of red and grey, respectively.

Fire Occurrence Drivers and Their Evolution Through Two Decades in Spain: Machine Learning and SHAP Spatial Variables Analyses

Fátima Arrogante-Funes[1,*], Adrián G. Bruzón[2], Patricia Arrogante-Funes[2], M. Lucrecia Pettinari[1] and Inmaculada Aguado[1]

1 *Universidad De Alcalá, Department of Geology, Geography and the Environment, Environmental remote sensing research group, Alcalá de Henares, Spain*
2 *Universidad Rey Juan Carlos, Departamento de Tecnología Química y Ambiental, ESCET, Madrid, Spain*

**Corresponding author:* fatima.arrogante@uah.es

Keywords: Fire occurrence, wildfires, wildfire drivers, random forest, shap variables

Challenge

Forest fires play a crucial role in shaping and sustaining Mediterranean ecosystems. However, their severity has escalated recently, leading to substantial socio-economic and human losses. Understanding the drivers behind these fires is imperative for effective mitigation strategies. This challenge aims to estimate and analyse the drivers of forest fire occurrence in Galicia, Spain, comparing the periods of 2000-2010 and 2011-2020. Leveraging spatial databases and remote sensing data, machine learning techniques will be employed to discern patterns and infer influential variables. By utilising SHAP (SHapley Additive exPlanations) values, a comprehensive understanding of the most significant factors contributing to fire ignition will be attained. The ultimate goal is to generate a spatial map highlighting the variable with the highest impact on fire origins.

Methodology

The study focuses on Galicia, utilizing Landsat path-row “203-031” scenes, following an initial investigation of fire regimes in the Mediterranean. Galicia was identified as having the longest fire season, mediumlow burned area, medium fire size, and moderate intensity and variability. The study comprises four main blocks: the dependent variable of the burned area and its estimation, explanatory variables, statistical analysis and spatialization of fire drivers. Moreover, this analysis was replicated over the two studied periods (2000-2010 and 2011-2020). The dependent variable is categorical, representing burned and unburned areas. Historical fire occurrence data spanning 2000 to 2020 is compiled from Landsat TM-ETM+ and OLI/TIRS images on the Google Earth Engine (GEE) platform. With 30-meter resolution, these images facilitate detailed characterisation, particularly of small fires (< 50 ha). The explanatory variables of fire occurrence or non-fire are grouped into climatic (mean temperature, annual temperature range, accumulated precipitation, annual Palmer Drought Index, lightning density), topographic (slope, aspect, elevation), vegetation (NDVI range, NDVI coefficient of variation and mean, fractional vegetation cover), and anthropogenic (Euclidean distance to urban/agricultural interface, agricultural/forestry interface, urban/forestry interface, pastures-forestry, distance to roads, distance to human settlements, population density, cattle density). If we focused on climatic factor, including it in the model is crucial, particularly as it influences the natural fire regime. Climate, including temperature and precipitation, significantly influences how a forest fire behaves. Additionally, seasonal patterns associated with climate changes, such as drought periods or rainy seasons, affect the occurrence of forest fires. Within the climatic factor, lightning strikes are a primary driver of naturally caused fires and a crucial variable in modelling fire drivers. Regarding the topography factor, altitude can affect fuel availability and atmospheric humidity, impacting ignition probability and fire spread. Terrain slope can influence fire speed, direction, and fuel accumulation. Additionally, aspect relative to the sun can determine exposure to solar radiation and, consequently, fuel temperature and dryness, critical factors in fire generation and spread. It is relevant to consider the vegetation variable through the Normalized Difference Vegetation Index (NDVI) in a study on the drivers of fire occurrence for several reasons. The NDVI provides a quantitative measure of vegetation density, plant stratum (grassland, shrubland, or tree) and health, enabling the assessment of vegetation fuel availability and condition. Moreover, changes in NDVI can indicate seasonal variations in vegetation biomass, thus influencing fuel load and fire susceptibility. Additionally, NDVI can reveal spatial vegetation patterns that may correlate with factors predisposing to fire ignition, such as proximity to urban areas or human activities. Finally, Variables related to urban-agricultural, agricultural-forestry, urban-forestry, and grassland-forestry interfaces are crucial in fire occurrence studies, as human activities make these areas more susceptible to fires. Inside the block of the statistical analyses, Random Forest is employed due to its high predictive potential and precision in fire modeling. It particularly excels in predicting fire occurrence and susceptibility. The analysis distinguishes between drivers associated with fire presence and absence. To execute the model, 80% of the sample is selected as the training dataset (train) to predict the remaining 20% (test). Regarding the spatialization of fire drivers, SHAP (SHapley Additive exPlanations) variables produce a map, enabling managers to identify the most influential factors in fire occurrence across different zones. This spatial analysis aids in targeted fire management strategies.

Expected results

The results of the models used to predict burned and unburned areas in Galicia for both periods demonstrate their effective operation. In the first period, commission errors for burned and unburned areas were 3.18% and 5.82%, while omission errors were 5.66% and 3.27%, respectively. For the second period, these error percentages are reduced, with burned areas showing an omission error of 3.68% and a commission error of 1.67% and unburned areas with 1.71% and 3.76%, respectively (Table 1).

The models exhibit high precision, reaching 95% for the first and 97% for the second models. Additionally, the Kappa coefficient surpasses 0.9 in both cases, confirming that the classification is not random (Table 1).

The analysis of the importance of explanatory variables in the occurrence of fires in Galicia revealed that, for the first study period, the percentage of forest cover, altitude and slope of the terrain, and the distance to roads were the major contributors to the model. In contrast, during the second period, the coefficient of variation of NDVI takes second place in the importance ranking (Figure 1).

Regarding the importance per pixel in Galicia (Figure 2), we observe greater heterogeneity than in the previous cases. In the first period, we find many pixels whose most important variable is livestock. In contrast, we see fewer pixels. Forest cover is of greatest importance for the random forest model in general. In the case of the second period, the heterogeneity is maintained, but we see a greater number of pixels in which forest cover is the most important.

In Galicia, the proportion of forest cover has proven to be the most critical variable influencing the occurrence of fires in both study periods. This area showcases significant altitude variations, with higher elevations featuring forested regions containing native species and reforestation efforts. Conversely, lower areas near the coast are notable for hosting extensive crops, indicating a greater anthropogenic influence. Galician forests cover 69% of the region's surface, with the remaining 31% comprising scrub and pasture formations. In summary, wooded areas exhibit higher forest cover than crops in the lower regions.

Altitude and slope emerge as two influential variables in fire occurrence. Studies in Portugal, a region similarly affected by fires with plant species and agricultural-forestry trends comparable to Galicia, concluded that increased slope enhances fire occurrence due to reduced water retention. They also noted the accessibility of altitude conditions, the distribution of human practices, and fuel availability. Biophysical factors, particularly vegetation cover, are significant in determining fire occurrence, especially in pine forests where altitude is crucial.

However, between 2010 and 2020, the coefficient of variation of the NDVI gained importance over the preceding topographic variables. This shift may be attributed to pests like the pine nematode (Bursaphelenchus xylophilus), causing desiccation and death of trees. The nematode, introduced in Portugal in 1999 through the wood trade, inflicts economic and ecological damage by inducing chlorosis, desiccation, weakening, and death of tree masses in Galicia and Portugal. Forest abandonment due to rural depopulation and ageing reduces forest care, leading to scrub and fuel accumulation. The vertical continuity of fuels, together with the presence of pyrophytic species, increases fire occurrence. Moreover, private property, accounting for 98% of these areas, plays a significant role in forest management, with older people using fire as a traditional forestry tool.

Given these factors and Galicia's general repopulation with exotic species, primarily eucalyptus and pine trees, creating homogeneous and continuous plant masses with high flammability, fire occurrence has increased. This elucidates why the tree cover variable is the most influential factor in fire occurrence.

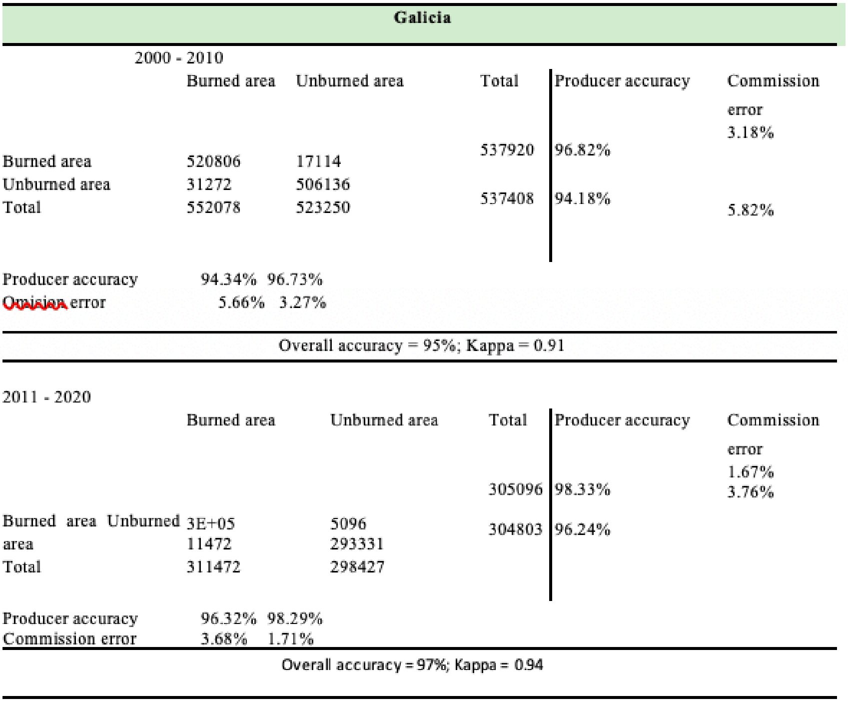
In examining the importance of explanatory variables in Galicia, the distance to roads also emerges as a relevant factor in fire occurrence. This reiterates the previously discussed relationship between the number of fires and the distance to roads.

In Galicia, the landscape's configuration across different bioclimatic levels, varying vegetation covers, forest abandonment, and fuel accessibility measured by distance from roads all confirm the human cause of fires.

Outlook for the future

This study represents an initial approach to estimate and discern the drivers of fire occurrence in a Mediterranean region such as Galicia. However, this investigation is part of a broader objective: to identify and assess fire occurrence drivers across two distinct periods under varying fire regimes worldwide. To achieve this, a global-scale fire regime mapping was developed as a foundational tool for identification. Moving forward, we aim to replicate this study in regions such as Bolivia, Canada, or Romania, each characterised by differing fire regimes according to the global fire regime mapping. Our future efforts will involve comparing fire occurrence drivers across these diverse locations to draw insights into global-scale fire occurrence and its temporal evolution.

Table 1. Confusion matrix for classifying burned and unburned areas using the Random Forest algorithm in Galicia.



Galicia

2000 - 2010

	Burned area	Unburned area	Total	Producer accuracy	Commission error
Burned area	520806	17114	537920	96.82%	3.18%
Unburned area	31272	506136	537408	94.18%	5.82%
Total	552078	523250			
Producer accuracy	94.34%	96.73%			
Omission error	5.66%	3.27%			

Overall accuracy = 95%; Kappa = 0.91

2011 - 2020

	Burned area	Unburned area	Total	Producer accuracy	Commission error
Burned area	3E+05	5096	305096	98.33%	1.67%
Unburned area	11472	293331	304803	96.24%	3.76%
Total	311472	298427			
Producer accuracy	96.32%	98.29%			
Commission error	3.68%	1.71%			

Overall accuracy = 97%; Kappa = 0.94

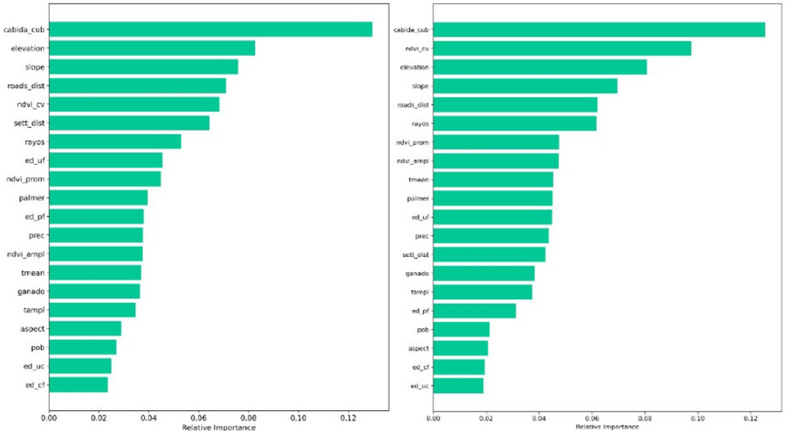


Figure 1. Importance of the variables used in the Random Forest model to classify burned and unburned areas in Galicia between 2000 - 2010 (left) and 2011 - 2020 (right).

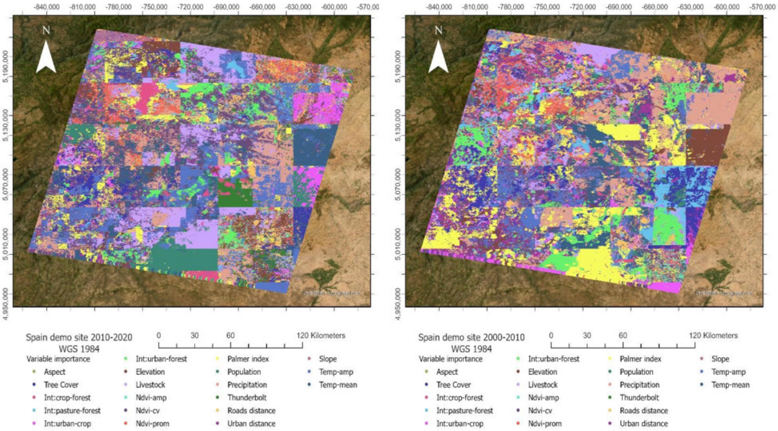


Figure 2. The importance of the variables used in the Random Forest model is measured by pixel to classify burned and unburned areas in Galicia between 2000 - 2010 (left) and 2011 - 2020 (right). See Table 1 for the identification of the explanatory variables.

Post-fire Dynamics of Habitat Heterogeneity in Mediterranean Landscapes Revealed by Time-series Analysis of Satellite Data

May Lechtman[1], Avi Bar-Massada[1,*]

1 University of Haifa, Department of Biology and Environment, Israel

**Corresponding author:* avi-b@sci.haifa.ac.il

Keywords: wildfire, FireCCI, regeneration, heterogeneity, time-series

Challenge

Habitat heterogeneity is a fundamental determinant of biodiversity patterns and is often generated by disturbance events such as wildfires. The effects of wildfires on habitat heterogeneity are complex, as they vary across space (via the spatial patterns of burn severity), and time (via differential regeneration mechanisms of plant species). Thus, to better understand biodiversity patterns, we need to expand our understanding of the role of wildfires in generating habitat heterogeneity dynamics. Here, we quantified the long term (20 years) spatiotemporal dynamics of habitat heterogeneity in landscapes exposed to wildfires, as reflected by post-fire time series of spectral indices. Specifically, we analysed the effects of pre-fire vegetation type, burn severity, and topography on the temporal dynamics of habitat heterogeneity.

Methodology

We used data from FireCCI to identify wildfire locations across the Mediterranean basin in 2001. For each fire pixel, we checked if no additional fire occurred from 2002 to 2021 to identify locations where succession was uninterrupted by subsequent fires. We further filtered out all fires smaller than 250 ha to reduce the likelihood of including mixed burned pixels. In the centroid of each remaining fire patch, we allocated a 100 m radius sampling buffer and extracted Landsat 7 NDVI values from all pixels inside it throughout the entire study period. In each buffer, we computed mean NDVI as a measure of canopy cover, and the standard deviation of NDVI (stdNDVI) as a measure of habitat heterogeneity. We also extracted the mean dNBR value from Landsat 7 in each buffer around the fire date as a measure of burn severity; the standard deviation of elevation from SRTM as a measure of topographic roughness; and the pre-fire vegetation type from FireCCI, restricting our analysis to natural land covers (broadleaved, conifer, shrubland, tree/shrub, natural, and grassland). For each buffer, we generated a 20-year time-series of meanNDVI and stdNDVI and fit a 2nd order polynomial curves to them using linear mixed models with a quadratic term, using each of the three predictors described above, as well as their quadratic interaction with time since fire.

Expected results

As expected, meanNDVI of all vegetation types increased nonlinearly throughout the 20 years period after the fires, reaching saturation after 16-20 years, but its values varied significantly among vegetation types (Figure 1 left). Broadleaved vegetation had the highest meanNVDI, followed by shrublands, conifers, tree/shrub mixtures, natural vegetation, and grasslands. Habitat heterogeneity exhibited more complex temporal dynamics, which varied significantly among vegetation types, and converged 20 years post-fire into two main groups: trees/mixed (high heterogeneity) vs. grasslands and shrubs (low heterogeneity) (Figure 1 right). Whereas natural vegetation, grasslands (and to a lesser degree, shurblands) exhibited an increase in stdNDVI through time, broadleaved and conifer forests exhibited negative stdNDVI trends, possibly reflecting canopy closure which is associated with reduced structural heterogeneity in forests. Burn severity (dNBR) had a significant negative effect on meanNDVI (reflecting the strongest reduction in photosynthetic activity after severe fires), but a nonsignificant effect on stdNDVI, possibly due to the differential responses of plant species to fires. Finally, topographic roughness had no effect on either meanNDVI or stdNDVI.

Outlook for the future

Our preliminary results revealed the complex effects of wildfires on the emergence of habitat heterogeneity in Mediterranean ecosystems. Specifically, the temporal dynamics of heterogeneity are driven by differential responses of vegetation types to fires, which reflect the evolutionary adaptations of the species that comprise them. Given the relative simplicity of our approach, there is much room for improvement. We are developing a comprehensive analysis, which will first identify fire perimeters at 30 m resolution instead of 250 m; and provide a better estimate of burn severity heterogeneity inside fire perimeters. This will facilitate a more representative sampling of regeneration dynamics and will enable us to utilize improved data on pre-fire vegetation, expand the sample size, and incorporate additional heterogeneity measures such as image texture metrics, as well as additional explanatory variables.

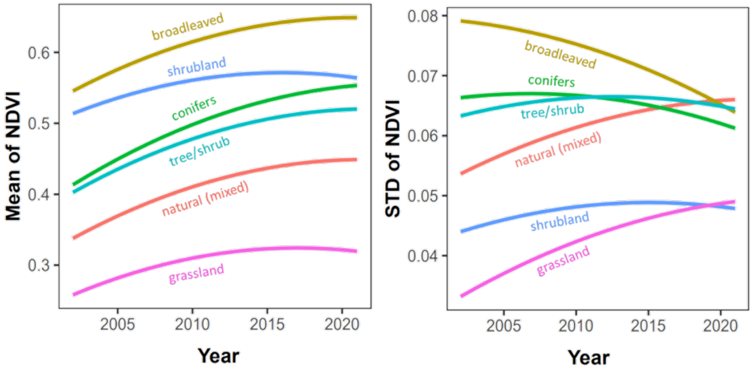


Figure 1. Temporal dynamics of meanNDVI (canopy cover), left, and stdNDVI (habitat heterogeneity), right. Curves are 2nd order polynomials fit to the data according to vegetation type.

Comparison of Fire Radiative Energy Estimates from the MODIS and VIIRS Active Fire Products

Jennifer Dodd[1], **Luigi Boschetti**[1,*], **Vladyslav Oles**[1]

1 University of Idaho, Department of Forest Rangeland and Fire Sciences, USA

**Corresponding author:* luigi@uidaho.edu

Keywords: MODIS, VIIRS, intercomparison, FRE, FRP

Challenge

Instantaneous estimates of the power released by a fire (Fire Radiative Power, FRP) can be retrieved from infrared satellite bands, and are generally available as part active fire detection product suites. The temporal integration of FRP in time provides an estimate of the total energy released (Fire Radiative Energy, FRE), which can be converted into burned biomass estimates, needed not only by the atmospheric emissions modeling community, but also as an assessment of the severity of the fire impacts on the ecosystem. FRP estimates are currently produced from the Terra and Aqua MODIS active fire products, and from the Suomi VIIRS instrument that is providing continuity as the MODIS sensors are nearing decommissioning. Differences in sensor design including spatial resolution (375m for VIIRS, 1km for MODIS), radiometric resolution, saturation temperature and swath size, translate into significant differences in number of active fire detections, and estimated power. Furthermore, while the two MODIS instruments provide on average four overpasses per day (two daytime / two nighttime), whereas only one daytime overpass and one nighttime overpass is available for VIIRS. In this work, we investigate how these differences translate into estimated FRE.

Methodology

In this work we compare the fire radiative power estimated from various sensor combinations (Terra only, Aqua only, Terra + Aqua, VIIRS) using previously demonstrated linear interpolation techniques for the temporal integration of FRP data. Four study areas are selected, in Africa, Australia, Brazil and United States, each corresponding to the extent of a full MODIS tile (approximately 10 x 10 degrees), and considering a full fire season (one to three months). The four study areas encompass a range of different landcover and fire conditions, from small fragmented fires to large and compact burned areas. For each study area we characterize the tradeoffs between the higher VIIRS spatial resolution (and in turn the higher number of active fire detections) and the lack of morning overpass, which negatively impacts the ability to accurately capture the variation of emitted FRP during the day, and the ability to estimate the duration of the fire at each pixel location.

Expected results

Preliminary results indicate that while the MODIS (MOD14/MYD14) and VIIRS 375m (VNP14IMG) FRP estimates describe the same overall patterns, and similarly characterize the evolution of individual fire events (see Figure 1), the differences in sensor characteristics and temporal sampling translate into significant differences in estimated FRE. We also observe significant difference across ecosystems, with the largest differences, predictably, in environments with a strong diurnal fire cycle, and a prevalence of small fires with low energy release. Conversely, using the MODIS and VIIRS burned area products (MCD64 and VNP64) as an additional input to extrapolate in space the FRE point estimates had the biggest impact on large, compact burned areas.

Outlook for the future

Our results reinforce previous studies, in pointing out that temporal sampling is a critical limitation in the use of FRP data from polar orbiting instruments, and that the lack of morning overpass further hinders our ability to estimate FRE from VIIRS observations. The results also show a large difference between the VIIRS and MODIS Aqua instantaneous FRP and integrated FRE estimates, despite the same afternoon overpass; as the MODIS sensors are phased out, this implies that there will be a significant discontinuity between MODIS and VIIRS time series of FRP observations.

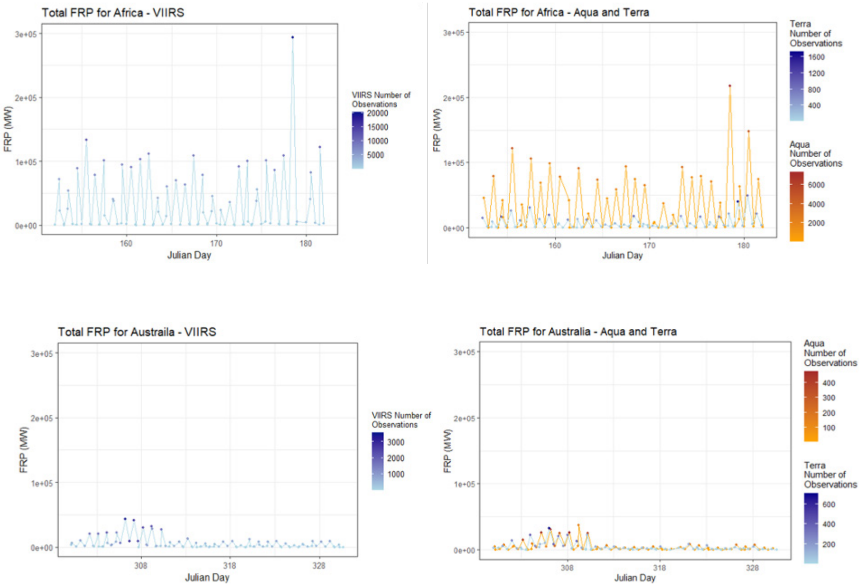


Figure 1. Sum of FRP values occurring in each VIIRS (left) and MODIS overpass (right, with red dots indicating Aqua and blue indicating Terra detections) for the Africa (top) and Australia (bottom) study area.

Comparative analysis of burned area mapping techniques using Sentinel-2 images of Google Earth Engine for México

Carlos Ivan Briones-Herrera[1,*], Daniel José Vega-Nieva[1], Adrián Israel Silva-Cardoza[1], Jaime Briseño-Reyes[1], Pablito Marcelo López-Serrano[1], José Javier Corral-Rivas[1], Juan Gabriel Álvarez-González[2], William Mathew Jolly[3] and João M. N. Silva[4]

1 Facultad de Ciencias Forestales, Universidad Juárez del Estado de Durango, México
2 Departamento de Ingeniería Agroforestal, Universidad de Santiago de Compostela, Escuela Politécnica Superior de Ingeniería, Lugo, Spain
3 USDA Forest Service, Missoula Fire Sciences Laboratory, Missoula, USA
4 Forest Research Centre, School of Agriculture, University of Lisbon, Lisboa, Portugal

**Corresponding author:* danieljvn@gmail.com

Keywords: burned area mapping; fire management; image composition; Kappa statistic, land use planning

Challenge

The increase in the frequency and intensity of forest fires has generated the need to develop efficient methods to map affected areas with free satellite images such as Sentinel 2. Despite the advances in the use of images, there are still challenges in the selection of optimal image composition or reduction techniques to improve the accuracy in the classification of burned and unburned areas. In addition, the use of temporal image compositions, such as 1- and 3-month images, can significantly influence the detection accuracy, but it is still unclear which one is best suited to better capture the effects of fire on ecosystems. This study addresses this knowledge gap by comparing eight image composition techniques using Sentinel 2 images processed in Google Earth Engine. The objective is to identify the technique that maximizes the accuracy in the classification of burned areas, using the Kappa index and RBRc. The results obtained will improve the capacity to detect and monitor burned areas, which will contribute to better decision-making in fire management and land use planning.

Methodology (1200 – 1500 characters incl. spaces)

The analysis utilized MODIS and VIIRS data for active fires and fire perimeters from the Mexican Forest Fire Hazard Prediction System. Sentinel 2 images were then employed to map burned areas within 17 aggregated active fire zones. For image analysis, a dataset from Sentinel 2, Collection 2a, was used. Challenges such as cloud cover were addressed by creating image composites over one-month and three-month periods to improve data quality. The study mapped the burned areas by calculating several indices, including the normalized burn rate (NBR), to obtain the difference between before and after with the differential normalized burn rate (dNBR) and the relative burn rate (RBR) to which in the sampling radius within a radius of 5 to 7 km the average value of the phenology was calculated using the VIIRS active fires to extract with the tool extract values to points the RBR and subtract them from the composite to reduce noise by phenology in the classification of burned area, which we call RBRc for its phenological correction for more details see Silva-Cardoza et al. 2022. The "reduce" technique included in the Google Earth Engine module, which has options to reduce the number of images and the pixels they contain, was used, then the "extract point values" tool was used (Figure 1). In the R software the percentiles were calculated to calibrate the GAM models TH = (a*s*RBRc), using the automatic or best optimum engine to obtain the highest kappa, only when the curve was parameterized with two curves it was adjusted manually, using the GAM and GAMAIR packages.

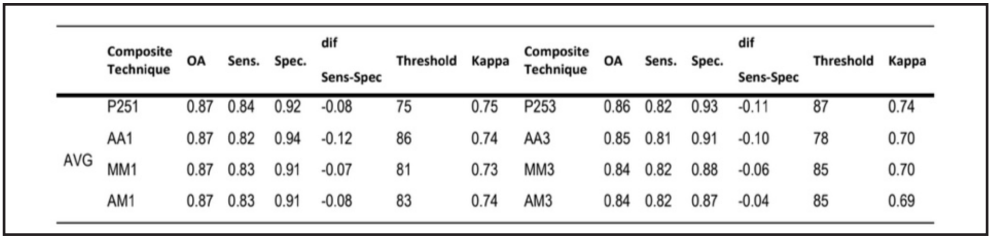
Expected results

Below is an average analysis of the techniques used to predict events, evaluating Overall Accuracy (PA), the Kappa Coefficient, and metrics of Sensitivity and Specificity. It is observed that some techniques yield better results than others in terms of these metrics, highlighting significant differences in their performance in predicting events (Table 1). The evaluation of various composition techniques revealed a significant finding: the P25 composition technique achieved a higher Kappa value compared to other methods. Given this promising result, the specific fire, 21OAX05, was selected for detailed examination and illustration in Figure 2. This fire was strategically chosen as it represented the general trends observed in the dataset. Upon closer examination of visual and statistical comparisons, a compelling pattern emerged: the P25 composition technique outperformed others in terms of visual clarity and statistical robustness. This case selection highlighted the ability of the P25 composition technique to accurately capture burned areas. Therefore, it became evident that the P25 composition technique stood out as the optimal choice for precise delineation of burned areas, underscoring its importance in this mapping effort. The value of the spectral index associated with the highest Kappa coefficient was determined as the optimal threshold for distinguishing between burned and non-burned areas within each composition and specific to each fire. Additionally, to comprehensively evaluate the effectiveness of the chosen approach, a thorough examination of the selected fire 21OAX05 was conducted. Its respective omission and commission errors were rigorously evaluated using the sampling points in Figure 2, with the maximum Kappa derived from the GAM as the threshold. This analysis provided valuable insights into the performance of the selected threshold in terms of minimizing false negatives and false positives. The results reaffirmed the suitability of the selected spectral index threshold and the overall effectiveness of the approach in accurately characterizing burned areas while minimizing classification errors.

Outlook for the future

The future of wildfire mapping and analysis holds promising prospects, driven by recent advancements in remote sensing, data analysis, and predictive modelling. Here are the key developments and directions anticipated to shape this field. Enhanced Precision in Fire Mapping: The P25 composition technique has proven successful in delivering high Kappa values, indicative of its accuracy in mapping burned areas. This finding suggests a significant opportunity to enhance fire mapping precision. Future efforts may involve refining this specific technique or developing new methods that improve the reliability and resolution of mapping outputs. The aim will be to ensure that fire delineations are not only precise but also consistent across various landscapes and conditions.

Table 1. Comparative analysis of burned area prediction techniques using different composite techniques.



	Composite Technique	OA	Sens.	Spec.	dif Sens-Spec	Threshold	Kappa	Composite Technique	OA	Sens.	Spec.	dif Sens-Spec	Threshold	Kappa
AVG	P251	0.87	0.84	0.92	-0.08	75	0.75	P253	0.86	0.82	0.93	-0.11	87	0.74
	AA1	0.87	0.82	0.94	-0.12	86	0.74	AA3	0.85	0.81	0.91	-0.10	78	0.70
	MM1	0.87	0.83	0.91	-0.07	81	0.73	MM3	0.84	0.82	0.88	-0.06	85	0.70
	AM1	0.87	0.83	0.91	-0.08	83	0.74	AM3	0.84	0.82	0.87	-0.04	85	0.69

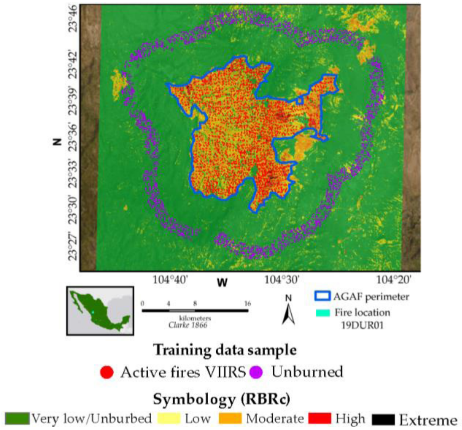
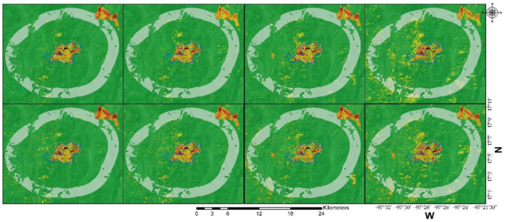


Figure 1. Methodology for sampling the RBRc in the 19DUR01 fire, the active VIIRS fires are represented by red dots. The VIIRS active fire count formed the basis for generating random unburned points, indicated by purple dots, located within the 5 to 7 km radius surrounding the fire site. The symbolization used for RBRc is based on the calibration presented in Silva-Cardoza et al. 2022.



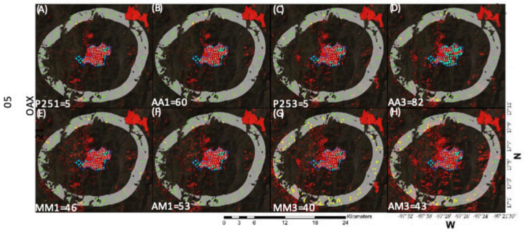


Figure 2 Different composition techniques applied to the 21OAX05 (A-H) forest fire. The acronyms include percentile 25 in pre and post (P251 and P253), Mean and Mean in Pre and Post (AA1 and AA3), Minimum and Minimum in Pre and Post (MM1 and MM3), and Mean and Minimum in Pre and Post (AM1 and AM3), both for 1 and 3 months. At the bottom of each figure its specific kappa threshold. Figures I-H show the sampled points of the burned areas (active fires) and their different errors. The burned and unburned areas are shown in red and black, respectively. For commission errors the points are shown in yellow on gray, for omission errors they are shown in turquoise blue on black. The gray points are correct classifications of burned area and the green points are the classification of the unburned area.

Automation of Geomatic Processes for the Forest Fire Danger Prediction System of México

Jaime Briseño Reyes[1,*], Daniel José Vega Nieva[1], Carlos Briones Herrera[1], Adrián Silva Cardoza[1], José Javier Corral Rivas[1], Pablito Marcelo López Serrano[2], Arnulfo Melendez Soto[1]

1 *Facultad de Ciencias Forestales, Universidad Juárez del Estado de Durango, Durango, México*

2 *Instituto de Silvicultura e Industria de la Madera, Universidad Juárez del Estado de Durango, Durango, México*

**Corresponding author:* jaime.briseno@ujed.mx

Keywords: geomatic, SIG, process automation, DSS, programming language

Challenge

The Forest Fire Danger Prediction System of Mexico (SPPIF) is a Decision Support System (DSS) for fire management in Mexico. Access to information is free through an Internet browser. The system presents the current situation, historical data, as well as animations of fire hotspots, fire perimeters, fuel dryness, expected number and location of fire events and burned area, and expected fire intensity (MW/km2), among other layers. The objective of this work is to present the use of innovative technologies and their integration in the automation of geomatic processes to generate the different information layers presented by the system. The use of geospatial databases and general-purpose programming languages such as Python, the potential that can be obtained in the geographic information process was observed. As a result, spatial information generated in almost real time as well as historical data has been obtained that supports decision making for fire management in Mexico, (Figure 1)

Methodology

To make it possible for the SPPIF to be able to display information in almost real time, it is necessary to automate each of the processes and have the capacity to store the information generated daily in a spatial database. This also allows analyzing historical information to make predictions, as well as having the ability to display historical information on a web map. This can be done by using a general-purpose programming language such as the Python language. Among the automated processes are:

MODIS and VIIRS hotspot processing

They are transferred several times a day to the SPPIF in vector shapefile format via the FTP service. Through the Python programming language and using the arcpy module from ArcGIS, it is processed, generating a daily accumulated file of hotspots that is intersected in a raster image through a spatial analysis, this allows the classification of hotspots into forest, interface, agricultural and fixed points. The generated vector information is stored in a PostgreSQL database using the PostGIS extension and the GDAL library. Indexes were created on the columns that store the geometries to optimize access. (Figure 2).

Mapping of the Perimeter of Large Forest Fires from the Aggregation of VIIRS and MODIS Active Fires

The 10-day hot spots are grouped to create clusters at a distance of 1125 m estimated by Briones (2020, 2022), this distance allows differentiating small fire events from each other, particularly in areas where small burns from agricultural expansion. The limit of each cluster is generated using a convex hull envelope and subsequently the union of polygons is done again by aggregation at 1125 m, (Figure 3).

Expected results

The generated vector information is stored in a PostgreSQL geospatial database, this allows making interactive queries and the creation of customized web maps. In addition, raster information layers are generated daily, such as NRT kernel density of observed VIIRS fire intensity -FRP- (MW/km2), and forecasts of expected VIIRS active fire density, number and burned area of active fire perimeters and expected fire intensity (e.g. Vega-Nieva et al. 2018, 2024), among others. The generated information is used as input for the Mapserver platform and Leaflet library to make interactive maps to visualize on the SPPIF, (Figure 4) .

Outlook for the future

New content planned to be added to SPPIF are research projects funded by World Bank and USFS-NORTHCOM, among others include:

1. Update SPPIF fuel moisture indices using GOES, VIIRS and NOAA weather forecasts for Mexico;
2. Include the visualization of NOAA smoke forecasts and GOES active fires in SPPIF;

It is expected to automate each of the processes to make their NRT visualization possible in the SPPIF.

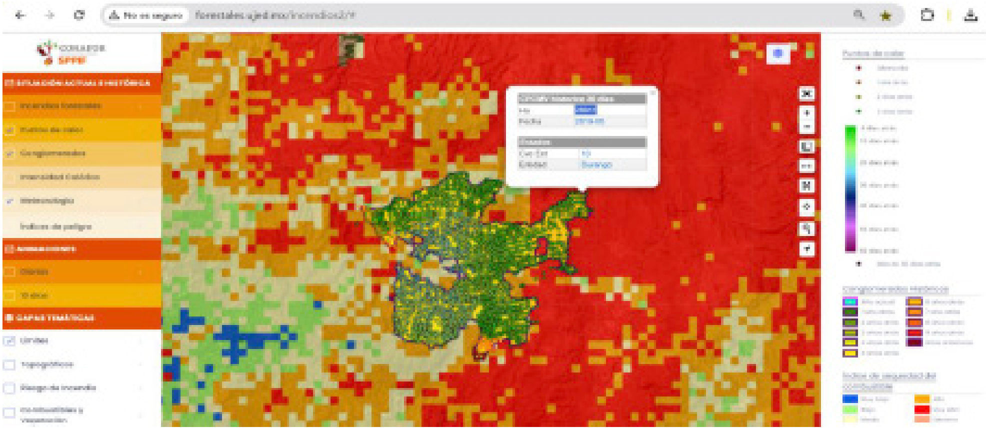


Figure 1. Forest Fire Danger Prediction System of Mexico (SPPIF). Fire perimeters are updated in NRT from MODIS and VIIRS active fires.

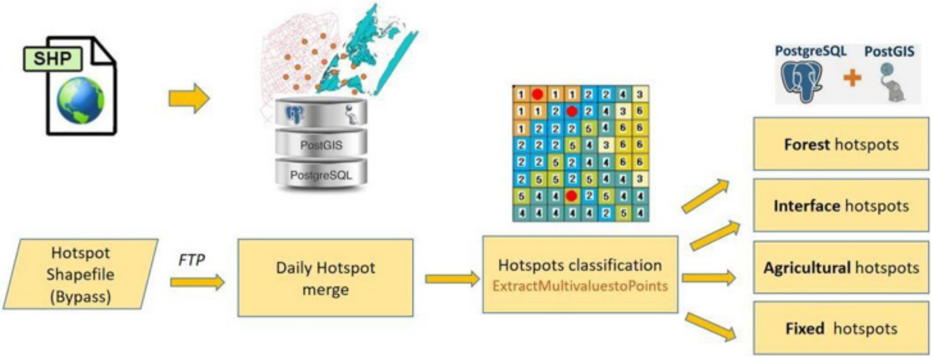


Figure 2. MODIS and VIIRS hotspot processing.

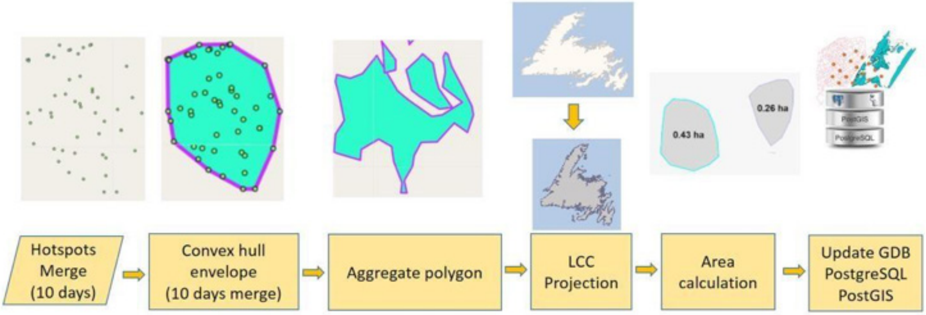


Figure 3. Mapping of the Perimeter of Large Forest Fires from the Aggregation of VIIRS and MODIS Active Fires.

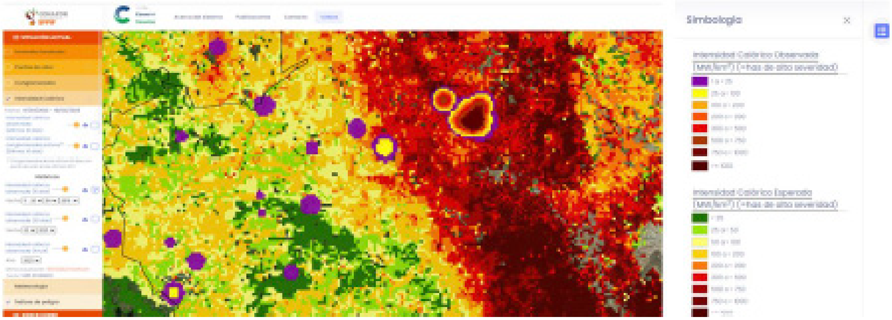


Figure 4. Expected and observed fire intensity -VIIRS FRP density (MW/km2)- in SPPIF

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Assessing the Impact of Wildfires on Lake Water Quality Worldwide from Satellite Data

Rossana Caroni[1,*], Monica Pinardi[1], Gary Free[1], Daniela Stroppiana[1], Lorenzo Parigi[1], Anna Joelle Greife[1], Mariano Bresciani[1], Luigi Lupo[1], Clément Albergel[2], Claudia Giardino[1]

1 CNR, Istituto per il Rilevamento Elettromagnetico dell'Ambiente (IREA), Milan, Italy
2 European Space Agency Climate Office, ECSAT, UK

**Corresponding author:* caroni.r@irea.cnr.it

Keywords: earth observation, Lakes_CCI Project, Fire_CCI project, wildfires, lake water

Challenge

This study aimed at investigating the effects of wildfires worldwide on lake water quality parameters, in particular detecting changes in satellite derived lake chlorophyll-a and turbidity. The selected lakes are located in different geographic and climatic zones and cover diverse lake morphological types and ecological settings. While many studies have focused on the effects of wildfires on terrestrial ecosystems and air quality, fire effects on water quality have been relatively overlooked until recently and much research focused on streams and rivers rather than lakes. The majority of previous lake studies were restricted in terms of lake number, geographical regions, and ecological contexts. There is therefore a need for global scale studies in order to assess the generalizability of the findings. Remote sensing techniques can be used to achieve these objectives by producing datasets providing global, objective, and consistent information on burned areas and water quality products.

Methodology

We used satellite products developed by two separate projects on lakes (Lakes_cci) and fire (Fire_cci) managed by the European Space Agency Climate Change Initiative (ESA CCI). We considered chlorophyll-a (Chl-a) and turbidity as indicators of water quality for the period from 2017 to 2020 built from OLCI-Sentinel-3 A/B data. We used the FireCCI51 Burned Area (BA) product, which shows the global spatio-temporal distribution of BA derived from MODIS satellite observations. Burned area maps are produced using a hybrid algorithm that blends active fire derived from thermal channels with the near-infrared surface reflectance. The product comprises monthly global maps covering the period 2001–2020 and burned pixels with estimated Julian day (DOY) of detection and the burned pixels cover category extracted from the Land Cover_cci v2.0.7 product. Burned pixels have been extracted from the FireCCI51 BA product for every lake catchment, using the R package "exactextractr". Lake and catchment characteristics data were obtained from the HydroLAKES and Hydro-BASINS datasets; they allowed the selection of sub-basins connected to each lake within 50 steps. Land cover data at lake catchment level was extracted from the Copernicus Climate Change Service for the period 2017–2020. We calculated the Standardized Precipitation Index (SPI) for each lake for the period 1980–2019 using ERA5 data of total precipitation for each lake watershed. Our lake data analysis focused on the period 2017–2020.

Expected results

Using the Source-Pathway-Receptor approach to describe transport of burned materials to lakes via terrestrial pathways, from an initial 2024 lakes a selection was performed using hierarchical cluster analysis (Sørensen distance with flexible beta linkage) to finally select 106 lakes potentially more prone to be affected in their water quality and thus considered in our analysis. Among many hydro-morphological lake characteristics considered in our analysis, we found that lake average depth was a significant factor for determining Chl-a peaks concentration, being higher in shallow than in deeper lakes (by ANOVA and multiple linear regression analysis), and ratio of burned area/burnable area as a secondary factor. Lake turbidity responses to fires indicated a dependence on lake catchment and local weather conditions, with the SPI as a significant factor for predicting turbidity peaks. Timing of Chl-a and turbidity peaks occurring after a fire was calculated and we found that lakes with a ratio BA/A > 0.25 and lakes in oligotrophic conditions tended to show a faster response in developing Chl-a peaks. When comparing pre- and post-fire lake water quality within a six-month period, lake Chl-a and turbidity either increased or decreased in a similar number of lakes, indicating that lake specific ecological context is important for explaining responses to wildfires (Figure 1).

Outlook for the future

In our study, the identification of significant relationships between wildfires and the response in water quality of lakes globally distributed proved to be a challenging task, in agreement with previous smaller scale studies. Generalizing findings proved to be difficult because of the many interactions among the variables involved, resulting in complex hydrological and ecological dynamics in lakes, eventually translated into water quality condition changes.

Future studies should incorporate nutrients data so that loads derived from wildfires and other sources can be partitioned with greater confidence to in-lake responses, and combine satellite data with hydrological modelling to better quantify the role of precipitation and runoff in explaining water quality changes due to fire effects. Although satellite remote sensing represents the most feasible approach for global analysis, providing data at required frequency and spatial scales, it might offer better ecological insights when combined with datasets from different sources.

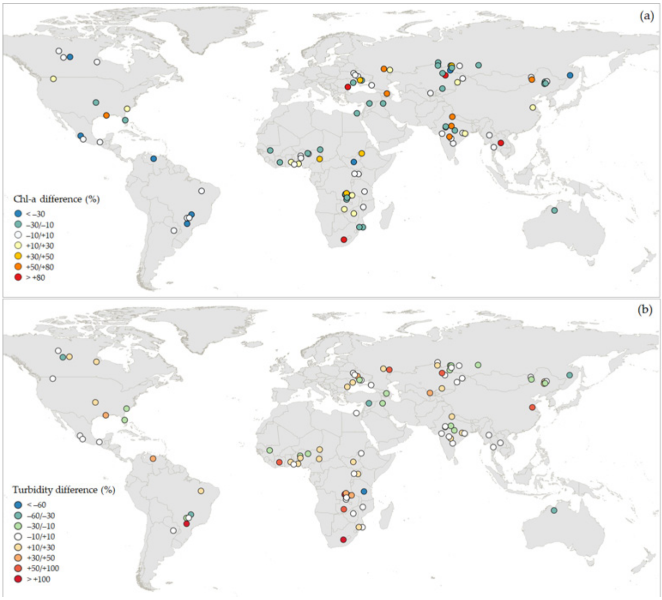


Figure 1. Global map showing geographical distribution of lakes with (a) Chl-a and (b) turbidity % change concentration over a six-month period after a fire.

Assessing the Performance of Copernicus Sentinel2 Fire Perimeter Datasets in 2021 and 2022 Fire Seasons: a Case Study from Sardinia

Liliana Del Giudice[1,*], Carla Scarpa[1], Michele Salis[1], Grazia Pellizzaro[1], Valentina Bacciu[1], Bachisio Arca[1], Pierpaolo Duce[1]

1 CNR, Istituto per la Bioeconomia (IBE), Sassari, Italy

**Corresponding author:* liliana.delgiudice@ibe.cnr.it

Keywords: earth observation, fire perimeters datasets, Copernicus, land use, Sardinia

Challenge

The availability of accurate wildfire perimeter data and related information is critical to wildfire management and prevention for several reasons. First, it is an essential base of knowledge for the understanding of fire ignition and spread patterns and the development of more effective prevention and management strategies. In addition, these data are crucial for assessing the impacts of wildfires on natural resources and highly valued resources, as well as for evaluating the economic and social costs associated with wildfires. The need of standardized and high-quality datasets at the National and EU level are in this sense very significant. In this work, we gathered wildfire perimeters of the events that affected the island of Sardinia (Italy) in the years 2021 and 2022. These data were collected from the European Forest Fire Information System (EFFIS) and the Sardinia Forest Service. Through a comparative analysis of the data, we will analyse the differences between the wildfire data coming from the abovementioned sources and will estimate the main sources of discrepancies between perimeters.

Methodology

As previously pointed out, the source data were obtained by EFFIS and the Sardinia Forest Service. By analysing satellite imagery, EFFIS maps burned areas for the whole EU Countries during the fire season; especially after 2018, the use of Sentinel-2 imagery has enabled the detection of single wildfire events below the 30-hectare threshold. The wildfire perimeter data collected by the Sardinian Forest Service are on the other hand mostly obtained through field observations, aerial overflights, and analysis of other sources. As a main rule, the primary collection methodology for wildfire perimeters is based on direct field observations and GPS mapping, although in case of very large events the data collection can be supplemented with satellite imagery. After having collected wildfire perimeters, we processed in a GIS environment the shapefiles and intersected them with a set of spatial layers, namely 10 m-Corine Land Cover+ 2018 and the 10-m Land Cover Map of Europe 2017. We then analysed the potential discrepancies related to the time of year when the fire events occurred by cross-referencing the two databases and checking whether the fires were detected in all months of the year or in a specific time window. Finally, wildfires were divided into size classes to see if the differences between the datasets depended on the final size and to analyse the level of agreement between the EFFIS and Sardinia Forest Service databases in the highest size class (> 500 ha).

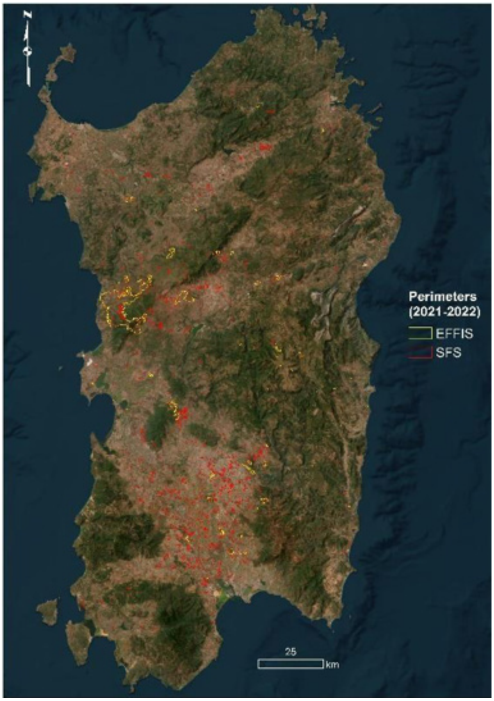
Expected results

The results show significant differences between the two databases. In particular, the first significant difference concerns the number of wildfires recorded. In the database of the Sardinia Forest Service, 2,098 wildfire perimeters and about 35,000 ha of area burned were recorded, while in the EFFIS database only 69 wildfires and about 20,000 ha were reported. This could be due to the fact that the Sardinia Forest Service also records events smaller than one hectare of final size, while the EFFIS database has limited data for this specific size class. Nevertheless, the differences between the two databases concerning wildfires that affected areas exceeding 500 hectares were not very significant. A contrast among EFFIS and Sardinia Forest Service data emerges regarding the types of land uses affected by wildfires. Within the EFFIS database, information about wildfires that predominantly impacted agricultural and pastoral areas is quite limited, while the Sardinia Forest Service perimeters include much more wildfires in these zones. It is likely that wildfires in agro-pastoral areas are not mapped in the EFFIS datasets.

Finally, although there is a temporal difference in fire mapping this is not marked and does not affect much in the comparison between the two databases.

Outlook for the future

EFFIS provides a comprehensive overview of wildfire situations in Italy and elsewhere, easily accessible to researchers and other stakeholders. Given the crucial role of accurate and standardized wildfire perimeters in forest fire management and prevention, even if the adoption of Sentinel-2 imagery has greatly improved the quality of the data provided by EFFIS for the EU scale, it would be important that further improvements in the quality and amount of wildfires maps will be guaranteed in coming years. The integration of satellite data with other data provided by individual Regions or specific Services, particularly if these local input data guarantees high quality standards, could facilitate and enhance a comprehensive mapping of wildfires. In addition, limiting wildfire mapping to events that exclusively or predominantly affect forests might represent a strong limitation in areas characterised by high presence of agro-pastoral land use types, such as observed in Sardinia and other neighbouring Mediterranean areas.



Wildfire perimeters gathered from EFFIS (in yellow) and Sardinia Forest Service (in red) for the 2021 and 2022 fire seasons in Sardinia, Italy.

Monitor Post-Fire Vegetation Dynamics in Forest Ecosystems at Monte Morrone (Abruzzo, Italy)

Federico Filipponi[1,*], Maurizio Sarti[2], Negar Rezaie[2], Francesca Adducci[3], Ettore D'Andrea[2]

1 CNR, Istituto di Geologia Ambientale e Geoingegneria (IGAG), Rome, Italy
2 CNR, Istituto di Ricerca sugli Ecosistemi Terrestri (IRET), Porano (TR), Italy
3 Tuscia University, Department of Innovation of Biological Systems, Food and Forestry, Italy

**Corresponding author:* federico.filipponi@cnr.it

Keywords: post-fire monitoring, carbon balance, Sentinel-2 MSI, biophysical indices, forest ecosystems

Challenge

Wildfires represent major disturbance in forest ecosystems and are recently increasing under climate change, regulating the carbon balance in terms of release of carbon dioxide (CO2) emissions and changes in growing stock volume. Satellite earth observation has been demonstrated to be an effective tool to characterize pre-fire conditions, quantify fire severity, and monitor post-fire dynamics. Primary damage due to wildfires on forest ecosystem can be estimated using fire severity as a proxy, based on differences in spectral and biophysical indices estimated from pre-fire and post-fire satellite acquisitions. Secondary damage due to wildfires may lead to forest dieback, that is the decline in vitality of a forest ecosystem. Medium and long-term time series of satellite-derived thematic information for the monitoring of post-fire conditions and trends can support the identification of forest dieback, besides the well-known monitoring of the recovery of natural ecosystems.

Methodology

Monte Morrone (Abruzzo region, Italy) has been identified as study site. It has been recently disturbed by two wildfire events, resulting in a surface of about 2000 hectares burned during August 2017 and about 400 hectares burned during July 2023. Vegetation in Morrone is represented by four distinct phytoclimatic belts, located at various altitudinal range: Mediterranean (below 400/500 m); sub-Mediterranean (500–900/1000 m); temperate Montane (900–1600/1700 m); and subalpine (above 1700 m). The forest types are evergreen oak woods (comprising 1 % of the area), deciduous oak woods (31 %), black pine stands (26 %), hop-hornbeam forest (11 %) and beech forest (31 %). Sentinel-2 MSI satellite data acquired over the period 2016-2023 were used for the analysis. Burned areas were mapped using a bi-temporal approach integrating multiple spectral indices. Burned area polygons distributed by EFFIS were used for comparison purpose. Within the burned area polygon, estimation of burn severity was evaluated subtracting a post-fire from a pre-fire Normalized Burnt Ratio (NBR) spectral index values, calculated from Sentinel-2 MSI satellite acquisitions:

$dNBR = NBRPRE-FIRE - NBRPOST-FIRE$

The dNBR values were used to determine burn severity level, according to threshold values proposed by the United States Geological Survey. Sampling points within the study area were identified by means of stratified random sampling, accounting for different burn severity levels and other selected variables. Specifically, three elevation zones were identified based on the specified ranges (e.g., deciduous forest between 300-600m, deciduous forest between 600-1100m, and evergreen forest above 1000m). Unburned area, used as reference for comparison, and two classes of burned areas, representing regrowth vegetation (indicating recovery) and burned vegetation (indicating severe damage or lack of recovery), were considered. Time series of Leaf Area Index (LAI) were generated from satellite optical multispectral data for the period 2016 - 2023, in order to monitor post-fire vegetation dynamics and identify trends, through linear regression. Field measurements for the collection of forest structure parameters and for deadwood assessment were performed inside circular buffers, centred on the sampling point coordinates identified by stratified random sampling analysis. Inside each plot, wood cores were collected from representative trees in terms of size and damages, in order to evaluate the post fire tree response. Field data were finally compared to the different trends identified from post-fire LAI and NBR time series.

Expected results

Burned area polygons generated using Sentinel-2 MSI data differ from polygons available from EFFIS. On one side, the EFFIS polygons delineate the edge of the burned area with greater approximation, on the other side, identification of burnt scars from Sentinel-2 data did not account for fire propagation in the understory with limited impact on tree canopy. In situ measurements are ongoing and will be completed in July 2024. Preliminary results show a faster recovery of natural grasslands ecosystems was found when compared against forest ecosystems. Some of the identified sampling points show LAI reduction in the post-fire, suggesting secondary damage due to wildfires. Positive slope of the regression line suggests post-fire vegetation recovery, while negative slope indicates potential forest dieback (Figure 1).

Fire impact of radial growth is hidden by the drought long stress effects. In fact, post-fire years were characterized by prolonged drought periods. Moreover, the competition reduction stimulated the growth of survived trees.

Outlook for the future

Preliminary results indicate that the exploitation of medium-term time series of the LAI biophysical index estimated from Sentinel-2 MSI satellite data is be a suitable tool to identify, describe, and monitor vegetation post-fire dynamics in ecosystems disturbed by wildfires (Figure 1). It could be used as complementary information to other spectral indices (e.g. NBR) largely used in literature for the monitoring of post-fire dynamics. Further analysis on additional study sites is required to validate the result on wider range of forest ecosystems. Among future perspectives of this research study, field measurements follow-up during year 2025 in the study area will enable continuation of trend monitoring, and foster strengthening of the results.

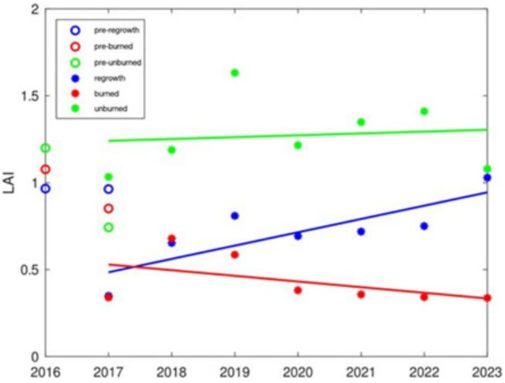


Figure 1. Vegetation dynamics observed in the period 2016-2023.

perform supervised classifications with a Random Forest (RF) algorithm to classify fire perimeters between each images pair (pre- and post-fire images). The input features for the classification include spectral bands as well as NDVI, NBR and NBR2 spectral indices. Over the same sites and classified fire perimeters, we applied pre-processing and extracted C-band SAR processed γ0 data, alas values independent from radar beam orientation, which was used for comparing the change in backscattered power after fire events. After categorizing the data using the NBR severity classes metric, an index of damage as quantified by the NBR difference in S2 pre- and post-fire acquisitions, the changes in backscatter and derived Radar Burn Ratio, Radar Burn Difference and Delta Radar Vegetation Index, were tested across the co- (VV, vertical-vertical) and cross-polarized (VH, vertical-horizontal) polarization bands. Finally, classification tests based on SAR backscatter power and radar indices, including different time configurations of the acquisitions, were carried out and validated by the optical-derived burned areas maps. SAR predictors importance was ranked using the Gini impurity index.

Expected results

The GEE application was developed for validation activities of the ESA FireCCI project and employed further in this work to assess SAR signal backscatter over burned areas, across various biomes and burn severity levels. S2-derived time maps of burned areas and associated burned/cloud vector layers were created for each site. Transferring this information to SAR S1 imagery, backscatter changes were extracted to test the statistical significance of signal power drops, due to post-fires variations of target roughness, geometry, and moisture content. Our analysis highlighted a significant change in distribution of both VV and VH samples for the majority of cases. Quantitatively speaking, while both polarizations displayed greater backscatter changes the higher the burn severity, the decline in backscatter power was more pronounced in the VH polarization. The classification tests for the S1 burned-area change detection highlighted the fact that SAR is still more suited for integration with multispectral, especially for compensating gaps caused by cloud cover or other disturbances that can hinder optical acquisitions, as multispectral still provided better results when the data was available. Still, our findings indicate that longer temporal baselines between SAR acquisitions identified fire events with greater accuracy, in the tested regions of high fire activity. Lastly, predictors

The Use of Sentinel-1 Synthetic Aperture Radar Data for Mapping Burned Areas

Alessandro Gatti[1,*], Marco Manzoni[1], Andrea Monti-Guarnieri[1], Giovanna Sona[2], Giovanna Venuti[2], Daniela Stroppiana[3]

1 Politecnico di Milano, Dipartimento di Elettronica, Iinformazione e Bioingegneria (DEIB), Milano, Italy
2 Politecnico Di Milano, Dipartimento di Ingegneria Civile e Ambientale (Dica), Milano, Italy
3 CNR, Istituto per il Rilevamento Elettromagnetico dell'ambiente (IREA), Milano, Italy

**Corresponding author:* alessandro.gatti@polimi.it

Keywords: earth observation, urban, hyperspectral, land use, Copernicus, burned areas, synthetic aperture radar

Challenge

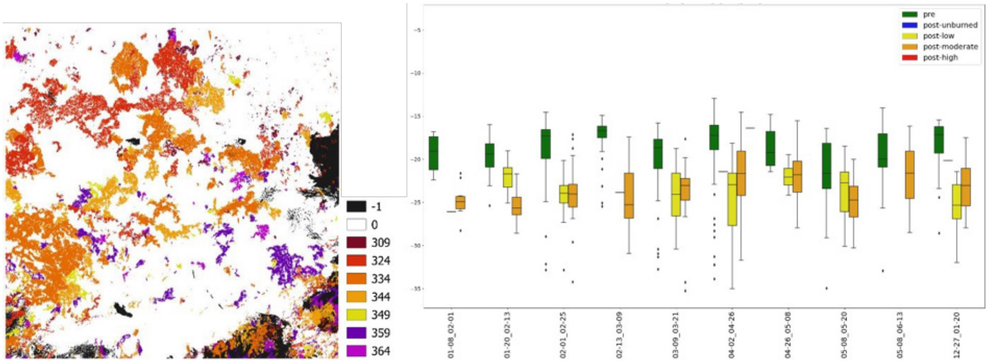
The impact of wildfires on global burned biomass and total greenhouse gas emissions can only be quantified with remote sensing techniques. This work revolves around the detection of burned areas from satellite images and the challenge of effectively integrating Synthetic Aperture Radar (SAR) in a multisource approach for monitoring wildfires and their impacts. The integration of multispectral (Sentinel-2, S2 and/or Landsat) and SAR (Sentinel-1, S1) images offer the possibility of taking advantage of the full-scale SAR acquisitions of target areas, independent from solar illumination and weather obstacles, and the multispectral visible and infrared spectral information suitable for monitoring damage by fires. This works first focused on the development of a Google Earth Engine application for generating burned area maps from multispectral bands and indices. From this, SAR signal backscatter was evaluated over burned areas. In a further step, SAR images were exploited to derive burned areas from classifications, using backscatter changes and radar indices; accuracy was assessed by comparison with fire perimeters generated from S2 images.

Methodology

Test sites in the three regions of interest, Sahel-savanna, Amazonia-rainforest and Siberia-boreal forest, were selected, and fire perimeters were derived from time series of Landsat and Sentinel-2 multispectral images with a custom developed Google Earth Engine (GEE) application. This software includes a designed user interface to values extracted from VV data were consistently ranked as more significant than the VH counterparts, suggesting that changes in soil moisture, more effectively identified by VV configuration, are more sensible to fires than the changes in geometry, better identified by VH, for the tested areas constituting of low vegetation and savanna landscapes.

Outlook for the future

Future development can expand the functionalities of the GEE application. Although the software currently uses Copernicus satellite missions' data, different sources of image data could be imported within the same architecture. Multi-source mapping could in fact enhance mapping accuracy for fire detection as well as for identifying other phenomena that induce changes on the surface. As SAR is a technology that has yet to be fully exploited, there is still room to progress its capabilities for both single data source detections and within an integrated framework. Use of longer temporal baselines to achieve better burn detection results can be investigated in different sites containing new biomes and/or fire regimes. The use of VV or VH independently, instead of a combined approach, can be explored as a possible optimization depending on the target type of soil and moisture content. More importantly, the combination of both backscatter and interferometry for detecting fire changes can be explored as the integration can most likely provide better insights into fire dynamics and impacts.



(a) Optical-derived burned areas perimeters mapped in time (doy). (b) Boxplot of SAR VH polarization backscatter power (y-axis) of pre and post-fire events, by burn severity levels.

Analysis of Post-fire Vegetation Succession Processes Using Class Membership Probabilities (RF), Multitemporal Vectors, and Trend Analysis Applied to Landsat Imagery

Cristian Iranzo Cubel[1,2,*], **Fernando Pérez-Cabello**[1,2], **Sergio Larraz Juan**[1,2]

1 University of Zaragoza, Department of Geography and Land Management, Spain
2 University of Zaragoza, Institute of Research into Environmental Sciences of Aragon (IUCA), Spain

**Corresponding author:* c.iranzo@unizar.es

Keywords: wildfire, trend, resilience, random forest, landsat

Challenge

Long-term (≈20 years) characterization of post-fire vegetation succession in areas with different reproductive strategies is crucial for understanding the effects of fire and identifying the suitable hydrological-forestry restoration measures. Supervised digital classification enables mapping of vegetation distribution pre and post-fire using resources like Landsat image collections, employing algorithms like Random Forest, resulted in class membership probabilities values (CMPv) for each eligible tree species. This study aims to characterize post-fire vegetation succession utilizing continuous CMPv data. Annual and multi-year composite products are examined using trend analyses (Mann-Kendall + Sen) and Multitemporal Vectors (MV) to understand change trends, intensity, and direction, alongside Mixed Gaussian Models (GMM) for spatial segmentation of regenerative responses.

Methodology

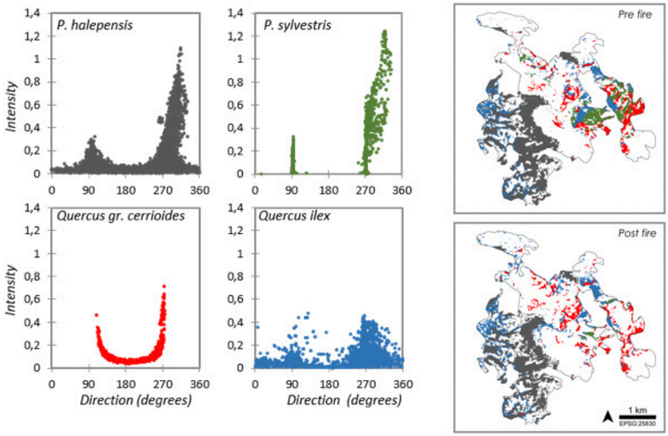
The study focuses on a forest fire in August 2001, representing an ecotonal zone containing formations with different reproductive strategies: Pinus halepensis (obligate recruiter), Pinus sylvestris (specie with passive fire resistance strategies), Quercus ilex and Q. gr. cerrioides (obligate resprouters), and their respective replacement shrublands. The main methodological stages include: (1) Generation of annual maps (1997-2023) on the spatial distribution of plant-communities, using time series of Landsat data (Level 2, Collection 2, available in the GEE platform repository), and the Random Forest (RF) supervised classification algorithm. Training points include the main affected plant-communities, sample-based from two field data campaigns (2013, 2023) and the 2nd-4th Spanish National Forest Inventory (SNFI). (2) Generation of multi-year composites representing the average CMPv before (1997-2000) and 20 years after the fire (2020-2023), selecting high-confidence pixels (leading class >50%). (3) Application of VM techniques to quantify the intensity and direction of changes in vegetation formations, considering different succession scenarios. (4) Trend analysis considering the year following the fire as the starting point using Mann-Kendall + Sen. (3) Application of Mixed Gaussian Models (GMM) using the Expectation-Maximization (EM) inference algorithm, with cluster selection based on the Bayesian Information Criterion (BIC).

Expected results

Taking into account the distributions of intensity and direction values, statistically significant differences have been detected among the main vegetation formations (Test K-S; p-value > 0.05). Two predominant directions are observed across the four vegetation formations (≈90° and ≈300°). The former corresponds to scenarios where pre-fire probability levels are maintained post-fire, while the latter represents situations characterized by a decrease in the probability of assignment to tree formations (i.e., high resilience), simultaneous to an increase in the probability of assignment to shrub facies (i.e., low resilience). However, the intensity vector reveals the differing magnitude of the described processes: while the oak forests and Aleppo pine forests exhibit low intensity (0.15), especially in the case of Quercus ilex, in Pinus sylvestris forests, we find high values (confidence intervals for the mean, ranging from 0.37 to 0.42), being particularly relevant in the case of the direction pivoting around 315°. Therefore, the relationships between direction and intensity vary greatly depending on the reproductive strategy of tree species. In this regard, the differing intensity levels exhibited by conifers with passive strategy versus oak and serotinous-thermodehiscent pine trees denote the lower flexibility of the latter.

Outlook for the future

Multitemporal Vectors (MV) provide key information about the direction and intensity of changes using continuous variables (such as assignment probabilities), minimizing assignment errors. This technique can complement analyses of nominal variables that use confusion matrices to evaluate changes between categories. Future research aims to expand into other ecosystems, integrating additional change analysis algorithms like Continuous Change Detection and Classification (CCDC), Continuous Monitoring of Land Disturbance (COLD), Vegetation Regeneration and Disturbance Estimates Through Time (VeRDET), Multi-index Integrated Change Analysis (MIICA), Space-Time Extremes and Features (STEF), or Bayesian Updating of Land Cover (BULC).



Scatter plot between Multitemporal Vectors (direction vs intensity) by plant-communities.

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1985-2020 Trends in Wildfire Burn Severity in Aragon, Spain

Raquel Montorio[1,2]*, Fernando Pérez-Cabello[1,2], Raúl Hoffrén[1,2], Cristian Iranzo[1,2]

1 University of Zaragoza, Department of Geography and Spatial Management, Spain
2 University Institute of Research into Environmental Sciences of Aragon, Spain

** Corresponding author:* montorio@unizar.es

Keywords: RdNBR spectral index, fire severity, fire regime, landsat, Mediterranean landscape

Challenge

In the current context of global change, numerous studies analyze the trends of the main variables that shape the fire regime to determine their trajectories and the foreseeable behavior of this phenomenon under different scenarios. Existing studies mainly focus on analyzing trends in the number of fires and burned area. These variables, although important, are not always the best indicators for measuring the effects of fire. In fact, from the perspective of fire ecology, severity (i.e., the impact of fire on the ecosystem) and its spatial distribution are considered more decisive in establishing recovery time. The studies that have explicitly examined severity trends are scarce, spatially unrepresentative, and present conflicting results. Therefore, the development of more studies and regional approaches is needed. This is precisely the objective of this research, focused on analyzing fire severity in Mediterranean forest areas in northeastern Spain.

Methodology

109 burned areas occurring in Aragon (NE, Spain) during the period 1985-2020 were analyzed in this study, covering approximately 100,000 hectares of forested land. For each of these areas, the RdNBR (Relative delta Normalized Burn Ratio) index was calculated using pre-fire information from the year before the fire and post-fire information from the two subsequent months of the fire year or the following year, depending on the short (ST) or long-term (LT) evaluation approach, respectively. In all cases, spectral information was derived from the calculation of median values of cloud-free Landsat images available for the corresponding period. Basic descriptive statistical values (i.e., mean, median, maximum, minimum) and the percentage of high-severity (HS) burned

area were calculated for each fire. For the latter metric, the threshold for high severity was set at the RdNBR value associated with a Composite Burn Index (CBI) of 2.25 points. After grouping fires by year, the 35-year time series was analyzed with the Mann-Kendall test, using the threshold $p \leq 0.05$ for statistical significance, and the Sen slope and its confidence interval to assess the magnitude of the trend and its reliability.

Expected results

The data on the number of fires and the burned area reflect high interannual variability. Mean values of short-term severity (RdNBR_ST) range from 600 to 1300, with an average around 850. The percentages of HS_ST burned area range from 40-90%, with an average around 70%. Statistically significant positive trends are observed in both metrics (p-value of 0.014 and 0.015; Sen slope of 5.905 and 0.997, respectively) in this temporal perspective (Figure 1). The trend becomes non-significant if the start of the time series is set from the year 1990. This indicates that the 1980s, and earlier decades if Landsat information were available, are crucial for the correct analysis of trends in fire severity. In the long-term approach, a significant decrease in the values of both metrics is observed, reflecting the ecosystem recovery process in the first year after the fire. The mean value of RdNBR_LT decreases to 350 points, and the percentage of area burned at HS_LT is mostly below 15%. There is no statistically significant trend in the long-term perspective for both metrics (p-value 0.902 and 1.000, respectively).

Outlook for the future

Results of the temporal analysis of fire severity reveal a statistically significant positive trend in its short-term evaluation, with a strong influence of the early years of the time series. The comparison between ST and LT results reflects that it is the former approach, referred to as fire severity, that clearly establishes the trends of this variable. The long term approach, referred to as burn severity, does not reflect the existence of trends, showing greater variability as a result of the different recovery dynamics of the affected ecosystems, conditioned by natural factors and human interventions. These results should be contrasted with other spectral indices and complemented with an analysis of the spatial distribution of HS areas that demonstrate if the spatial pattern of these HS patches is changing. All of this provides valuable information about the current behavior of forest fires, which is relevant for the design of post-fire management actions.

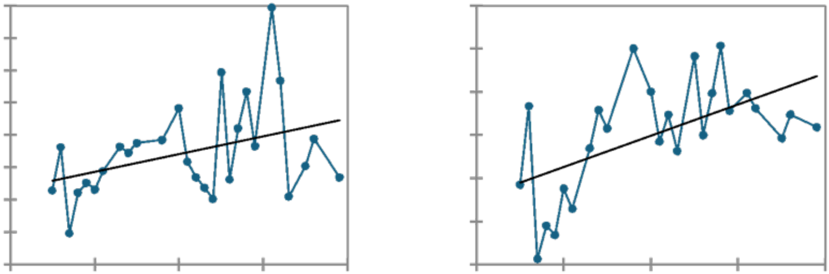


Figure 1. (left) Trend of mean RdNBR values in the short-term approach (RdNBR_ST) and (right) Trend of area burned at high severity level in the short-term approach (HS_ST).

The Comparison of 1D and 3D-CNN Classification of Satellite Observations for Wildfire Susceptibility

Antonia Ivanda[1,*], Ljiljana Šerić[1], Darko Stipaničev[1], Damir Krstinić[1], Marin Bugarić[1], Maja Braović[1]

1 University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Department for Modelling and Intelligent Systems, Croatia

**Corresponding author:* asenta00@fesb.hr

Keywords: fire propagation potential, Sentinel-2, 1D-CNN, 3D-CNN, classification

Challenge

This study aims to enhance fire and wildfire risk prediction using Empirical Fire Propagation Potential (FPP) as a quantitative measure describing the circumstances under which fires spread. While some fires are easily extinguished and pose minimal danger to vulnerable areas, others can escalate into large fires with devastating consequences for people, the environment, and economies. The paper evaluates FPP calculation based on Sentinel-2 satellite images leveraging different convolutional neural networks (1D and 3D). Extracting FPP from satellite earth observations requires problem formulation and comprehensive spatial, temporal and spectral analysis of data. Convolutional neural networks (CNN) are a convenient tool for automatic feature extraction and classification capable of learning from data but performance varies with selection of data format. In our research we analyse the appropriateness of 1D and 3D-CNN for predicting FPP.

Methodology

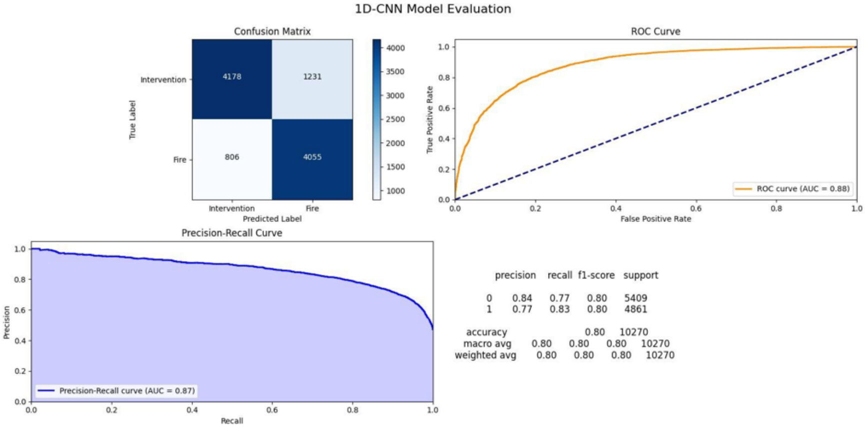
The study area of this research is Split-Dalmatia County in Croatia. To train and test 1D-CNN and 3D-CNN, we created supervised datasets based on Sentinel-2-L2A atmospherically corrected imagery with a 60m resolution. FPP is quantified as either 1 for a fire that has spread over a noteworthy area or 0 otherwise. Past fires detected by satellites and recorded in the European Forest Fire Information System (EFFIS) are considered situations where FPP is valued at 1. To assess situations where FPP is 0, we analyzed the fire intervention database maintained by fire services and filtered out only short interventions that relate to wildfires lasting less than two hours and involving two or fewer firefighters. We extracted 12 values of reflectances for each of the Sentinel-2 bands representing fire or short intervention. For the 1D-CNN, we utilized a balanced dataset with 54,094 data points for FPP=0 and 48,604 for FPP=1 in 2020. For the 3D-CNN, a balanced dataset was created for significant fires that occurred on April 8th and August 10th, 2020. Additional interventions occurring 2-3 days after these dates were included to ensure balance. The data cubes have a 3x3 window size, totaling 413 for FPP=0 and 619 for FPP=1. For both models, the dataset was split 80% for training and 20% for validation and testing. Evaluation is performed by comparing classification evaluation measures - confusion matrix, accuracy, precision, recall, f1-score, support, ROC and AUC curve.

Expected results

Earth observation data can provide insights on Earth surface features in spatial, temporal, or spectral feature dimensions. Convolutional neural networks are capable of extracting those features from provided data automatically. Features related to fire propagation potential, leading to fire extinguishing or spreading, can be found in both spectral and spatial dimensions. While 1D-CNN looks only at the spectral value of one pixel, 3D-CNN is capable of extracting spectral and spatial context by looking at the spectral values of surrounding pixels. Thus, we expect 3D-CNN to be capable of constructing a model that better estimates FPP, having more data for inference. This is proven by experiments carried out in this research. Figure 1 displays the evaluation results of the 1D-CNN, while Figure 2 presents the results of the 3D-CNN model. It is evident that the 3D-CNN outperformed the 1D-CNN, achieving an overall accuracy above 90%, which is consistent across each class, indicating that the model is not overfitted. In contrast, the overall accuracy for the 1D-CNN is 80%, with similar accuracy observed for each FPP class. Comparison of all evaluation measures demonstrates the superior performance of the 3D-CNN for predicting FPP.

Outlook for the future

We developed two empirical models for predicting FPP from satellite Earth observation: 1D-CNN, which utilizes only spectral features of Earth surface reflectance, and 3D-CNN, which utilizes both spectral and spatial features. By comparing the performance of 1D and 3D-CNN on the task, we conclude that the 3D-CNN yields better evaluation metrics when compared to the 1D-CNN-based model. The model used is trained on wildfires that occurred in 2020 on the territory of Split-Dalmatia County of Croatia. To improve the results and test generalization, the model will be trained on larger areas and longer periods of data. However, while satellite data and wildfire burned area data are available globally, short fire interventions are not easily retrieved. Thus, we will focus on regions that have archives of fire intervention reports available as study areas for training the model. We will also evaluate the results on future fires globally.

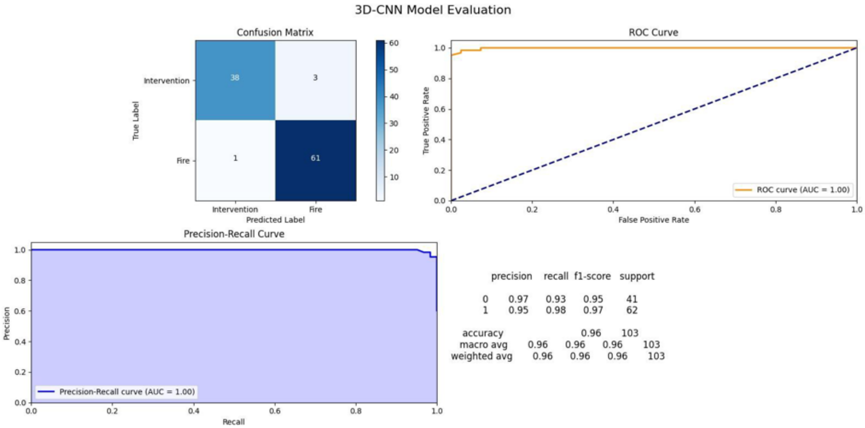


```
              precision    recall  f1-score   support

           0       0.84      0.77      0.80      5409
           1       0.77      0.83      0.80      4861

    accuracy                           0.80     10270
   macro avg       0.80      0.80      0.80     10270
weighted avg       0.80      0.80      0.80     10270
```

Figure 1. 1D-CNN evaluation metrics (confusion matrix, precision, recall, f1-score, ROC Curve and Precision-Recall Curve).



```
              precision    recall  f1-score   support

           0       0.97      0.93      0.95        41
           1       0.95      0.98      0.97        62

    accuracy                           0.96       103
   macro avg       0.96      0.96      0.96       103
weighted avg       0.96      0.96      0.96       103
```

Figure 2. 3D-CNN evaluation metrics (confusion matrix, precision, recall, f1-score, ROC Curve and Precision-Recall Curve).

Mapping Wildfire Scares – NDVI vs. NBR vs. AFRI

Arnon Karnieli[1,*], **Manuel Salvoldy**[1]

1 Ben Gurion University of the Negev, The Remote Sensing Laboratory, Israel

**Corresponding author:* karnieli@bgu.ac.il

Keywords: burn severity, change detection, sentinel-2, multi-temporal

Challenge

Wildfires have become serious human and environmental concerns in recent years for several reasons. Most importantly, they threaten human life, flora, and fauna, as well as properties and economic losses. Wildfires are considered one of the worst ecological disturbances to long-term records of vegetation phenology since land-cover alterations are the basis for understanding the biological responses to climate change, such as impacting carbon emissions, at regional to continental scales. The effect of wildfires on biodiversity, plant reproduction, forest succession, habitat quality, hydrologic regimes, and soil characteristics, such as nutrient cycling, is also worth mentioning. For all the reasons discussed above, different technologies have been developed for detecting and monitoring various aspects of wildfire, including risk assessment, active fire detection, gas and aerosol emission, smoke penetration, and temporal dynamics of burned areas. Among all technologies, there is a general agreement that remote sensing techniques are essential for providing valuable data for detecting, monitoring, interpreting, and responding to wildfires from local to global scales.

The current project strives to develop and use an advanced Earth observation approach for accurate post-fire spatial and temporal assessment shortly after fire events while eliminating the influence of biomass-burning smoke on the ground signal.

Methodology

The Aerosol-Free Vegetation Index (AFRI), Eq. 1, which has a meaningful advantage in penetrating an opaque atmosphere influenced by biomass-burning smoke, was used to fulfil this goal (Karnieli et al. 2001; Salvoldi et al. 2020). The relative deference AFRI (RdAFRI), Eq. 2, set of algorithms was implemented using the same procedure commonly used with the Relative deference Normalized Burn Ratio (RdBRN). Similar to the NBR, the Aerosol-Free Vegetation Index (AFRI) is also based on the correlation between the visible-red and the SWIR2 band:

$$\text{APRI} = (\rho\text{NIR} - 0.5\rho\text{SWIR2}) \;/\; (\rho\text{NIR} + 0.5\rho\text{SWIR2}) \qquad (1)$$

where ρ is the reflectance value of the indicated spectral band – NIR and SWIR2 (around 2.1 µm).

The study was conducted nine months when Israel experienced massive pyro-terrorism attacks of more than 1100 fires from the Gaza Strip. 25 Sentinel-2 Level-2A products were selected with cloud coverage inferior to 15% from 6 April 2018 to 22 December 2018 in order to monitor the study area during the kite and balloon attacks period. The NIR band (B8) and the SWIR2 (B12), at 10 and 20 m spatial resolution, respectively, were used to calculate the relevant spectral indices. Similar to the procedures developed for the NBR-based set of algorithms, the most intuitive burned area-mapping indicator consists of an absolute change detection methodology obtained by subtracting a post-fire AFRI image from a pre-fire AFRI image to derive the deference AFRI (dAFRI):

$$\text{dAFRI} = \text{AFRIt0} - \text{AFRIt1} \qquad (2)$$

Then, the dAFRI, for two successive images collected in this study, can be formulated as:

$$\text{RdAFRI}(i-1, i) = \text{AFRI}(i-1) - \text{AFRI}(i) \text{ with } i = 2,\text{⍰⍰⍰},25 \qquad (3)$$

where (i) indicates the i-th image in the database. The dAFRI(i-1, i) can present problems in the cases with low vegetation values for the image taken at (i-1): the absolute change will be small, and the index will not be able to detect the burned area. In order to avoid this issue, the relative differenced AFRI (RdAFRI) was defined as:

$$\text{RdAFRI}(i-1, i) = \text{dAFRI}(i-1, i) \qquad (4)$$

$\text{AFRI}(i-1)$ /1000

Positive RdAFRI(i-1, i) values represent a decrease in vegetation cover, while negative values represent an increase in vegetation cover.

Expected results

For comparing the performance of the NBR, NDVI, and AFRI indices, a section of the S2 Level-2A image obtained on 10 July 2018 is presented in Fig. 1.

The transects represent a common situation when smoke, at different intensities, covers a variety of substrates—cultivated, bare soils, fire scars, and more. The true-colour composite image (RGB = 0.665, 0.56, 0.49 µm) shows the open fire (light-orange hue), the biomass burning smoke (white hue), as well as burned scars that are a few days old (dark surfaces). The three indices were produced at 10-m spatial resolution, according to Equations (1), (2), and (5), from the surface reflectance values along a cross-section of 2771 m. This line was selected since it passes cultivated fields, bare soil, and was overcast by light smoke that characterized the entire region during the study period. This line is subdivided into several segments. From pixel 0 to 50 (and similarly from pixel 180 to 190) over the agricultural field where no smoke exists, the AFRI values accurately mimic those of the NDVI, but the NBR values are significantly lower. From pixel 50 to 180, AFRI values are somehow higher than those of the NDVI over the bare soil. However, the NBR values are negative and much lower. From pixel 180 to 318, under the smoke, the AFRI values of the crops remain at the same high level as in the smoke-clear section, while both the NDVI and NBR produce low values.

While validating with ground observations, the RdAFRI-based algorithms produced an overall accuracy of 87% against the 80% obtained by the RdNBR-based algorithm. Furthermore, the RdAFRI maps were smoother than the equivalent RdNBR, with noise levels two orders of magnitude lower than the latter (Fig. 2). However, an automatic threshold level was not possible due to different cloud covers on the two consecutive dates. Therefore, two threshold levels were considered through visual inspection and manually assigned to each imaging date.

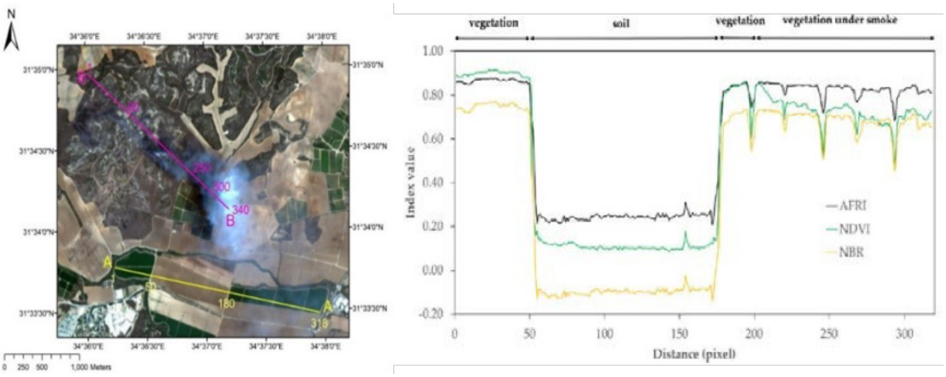


Figure 1. Left Panel - A true-colour (RGB = 0.665, 0.56, 0.49 μm) daily surface reflectance image of the Israeli territory on 10 July 2018. The open fire appears in a light-orange hue, the burn scars are dark, and the smoke is a white hue; Right Panel - AFRI, Normalized Difference Vegetation Index (NDVI), and Normalized Burn Ratio (NBR) values along a cross-section on 10 July 2018. The x-axis numbers represent the pixels' distance along line A–A in accordance with the Left Panel.

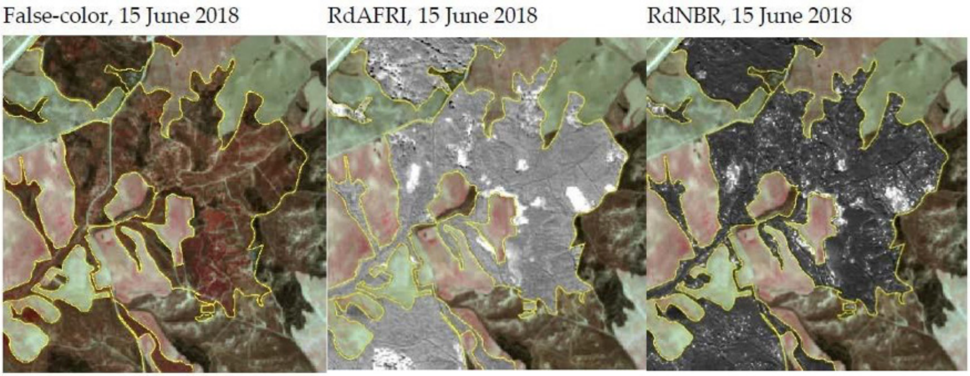


Figure 2. False-colour image with the corresponding RdAFRI and RdNBR images.

Outlook for the future

Wildfire is a complex issue related to ecosystem changes, climate, land use and land cover, and management practices. It also has many socio-economic implications. Therefore, maps of fire scars provide valuable information for studying forestry, agriculture, pedology, as well as climate change. Since Earth observation data are considered the most informative means for quantifying the scars, a large variety of space systems have been used for this purpose. Selecting the most appropriate satellite depends on several criteria. Obviously, the large-swath satellites (e.g., NOAA-AVHRR, MODIS) are more suitable for the continental to global scales. In contrast, high spatial resolution and narrow swath are preferable for a regional scale. The second criterion is the temporal resolution required for the specific application. The number of fires, burned areas, as well as derived environmental consequences, such as the amount of CO2 emissions, are usually summed for a monthly, seasonal, or yearly period using the large-swath satellites. However, for fast response and accurate mapping (e.g., for insurance assessment), more frequent images from high-resolution satellites (e.g., Sentinel-2, VENμS, RapidEye, etc.) are essential. Thirdly, the most meaningful spectral index for enhancing the burned signal and differentiating severity levels must be identified. Concerning the study objectives, S2 was found to be a suitable satellite due to its characteristics—high spatial resolution of 10 m, high temporal resolution of about five days, and the SWIR bands for computing the AFRI.

On the Potentiality of the Sentinel-1 for Fire Severity Assessment: the Experience of FIRESAT project

Rosa Lasaponara1,*, Nicodemo Abate2, Angelo Aromando1, Guido Loperte3, Giovanni Di Bello3

1CNR, Istituto di Metodologie per l'Analisi Ambientale (IMAA), Tito Scalo (PZ), Italy
2CNR, Istituto di Scienze del Patrimonio Culturale (ISPC), Tito Scalo (PZ), Italy
1Regione Basilicata, Potenza, Italy

**Corresponding author: nicodemo.abate@cnr.it*

Keywords: Sentinel-1, FIRESAT, fire severity, SAR, Machine Learning

Challenge

Remote sensing plays a key role in wildfire monitoring. This paper explores the challenges inherent in fire severity assessment and damage estimation using radar-based Sentinel-1 sensors in comparison with optical image-based Sentinel-2. Indeed, while Sentinel-1 excels at penetrating smoke and cloud cover, providing temporal coherence and backscatter intensity variations, Sentinel-2 offers spectral information crucial for delineating fire extent and severity, and for this reason, is more widely used in this field. Understanding the strengths and limitations of each sensor type is crucial for effective fire management and mitigation efforts. This study, part of the FIRESAT project, aims to address the study of fires and fire severity using Sentinel-1 (bands and indices), machine learning operations (ISODATA), and spatial data aggregation (LISA).

Methodology

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 burned and unburned areas were observed in the VH polarization of both RBD and RBR. The novelty of our approach is based on the use of three steps data processing devised to identify different levels of fire severity without using fixed thresholds. The burned areas are first: 1) highlighted using the ratio between multitemporal data set acquired before and after the fire occurrence; 2) further enhanced by Getis-Ord spatial statistic; and 3) finally, categorized using ISODATA unsupervised classification. The approach herein proposed pointed out that: 1) the time-averaged ratio of VH polarization of Sentinel-1 well perform in mapping burned area and 2) the use of Getis-Ord spatial statistic coupled with ISODATA unsupervised classification suitably captures the diverse levels of burned severity as confirmed by in situ assessment.

Expected results

The present study aims to obtain a study map for wild fires using the Sentinel-1 SAR sensor. In particular, fire severity maps will be obtained using SAR bands (VV and VH) as well as RBR and RBD indices that are comparable to those obtained from optical sensors (Sentinel-2 and MODIS) and published by independent research and accredited providers (EFFIS). The result will be to have a severity map that can be correlated with those of the optical sensor but with the added value of being able to obtain useful data for studying events and damage regardless of weather and atmospheric conditions by exploiting the potential of SAR. The greatest achievement will be to obtain maps semi-automatically by means of complex machine learning algorithms and spatial clustering analyses such as LISAs (Local Indicators of Spatial Association). The results will be scalable and replicable as the entire flowchart is developed with completely open source tools and data made freely available on a global scale with a weekly or biweekly review time. In addition, one of the results will be the study of fire severity indicators completely unrelated to the thresholds currently used to study this phenomenon using optical sensors (e.g. USGS thresholds) so as to overcome the limits dictated by local phenomena (e.g. thresholds studied for the tropical or temperate zone).

Outlook for the future

In the future, it is planned to develop the FIRESAT project with an implementation of optical and SAR sensors in order to obtain correlated and complex maps regardless of geolocation and local weather conditions. The approach will be to use a multi-sensor, multi-temporal method based on the aforementioned sensors and machine or deep learning algorithms for the automatic segmentation of fire areas and fire effects. The direction of the project will be to use free cloud computing tools for fast data processing and the creation of maps in near real time so as to function as a valuable support to the practical activities of understanding, monitoring and managing events and the damage they cause. To this will be added the study of vegetation loss indicators aimed at establishing the actual loss of biomass, economic damage and the dispersion of CO2 into the atmosphere.

Exploring the Time-lag Effect of Meteorological and Vegetation Features on European Summer Wildfires with Explainable Artificial Intelligence (XAI)

Hanyu Li[1,*], Stenka Vulova[1,2], Alby Duarte Rocha[1], Birgit Kleinschmit[1]

1 Technical University of Berlin, Department of Landscape Architecture and Environmental Planning, Geoinformation in Environmental Planning Lab, Germany
2 University of Kassel, Department of Environmental Meteorology, Institute for Landscape Architecture and Landscape Planning, Germany

**Corresponding author:* hanyu.li@campus.tu-berlin.de

Keywords: fire risk, earth observation, vegetation, explainable analysis, machine learning

Challenge

Wildfires are among the most destructive natural disasters. In recent years, global warming has further exacerbated the frequency and severity of wildfires. Identifying the driving factors behind wildfires and their impacts has become ever more urgent. Wildfires are the outcome of various interrelated factors. A comprehensive understanding of the potential connections between preceding meteorology, vegetation conditions, and fire activity across all of Europe is still lacking. Studies have established machine learning models for predicting fire occurrences with Earth observation data. However, most of them are not very interpretable and thus not very useful to furthering understanding of environmental processes. Explainable artificial intelligence (XAI) can allow us to understand the factors and conditions driving wildfires in time and space. Despite its potential to better guide management and prevention measures, XAI has rarely been used in the field of wildfire science so far.

Methodology

Our study area encompasses the entire European region, including forests, shrublands, and herbaceous vegetation. The research period spans 2018 to 2022. Based on relevant literature, we have selected features that can be categorised into four main groups: i) meteorology ii) vegetation, iii) topography, and iv) anthropogenic activity. For each year, pixels of burn areas in August were designated as fire points, while areas where no fires occurred from September of the preceding year to August of the current year were marked as non-fire points. Employing the Long Short-Term Memory (LSTM) method in conjunction with spatio-temporal cross-validation, we constructed a model to predict the occurrence of summer wildfires in Europe. LSTM is a deep learning model commonly used for handling sequential data, representing a variant of Recurrent Neural Networks. Subsequently, we employed the SHAP (SHapley Additive exPlanations) method to interpret the model. SHAP is a post-hoc XAI method with a solid theoretical foundation rooted in the coalitional game theory which strives to convert the model's predictions into a more comprehensible format. Then we can obtain the contribution of each feature for August wildfires in each month and assess the lag effects of climate and vegetation on wildfires.

Expected results

Model. We will obtain a wildfire occurrence model applicable across the entire European region. Using this model, we will predict the occurrence of August wildfires based on the one-year time series data of the selected features.

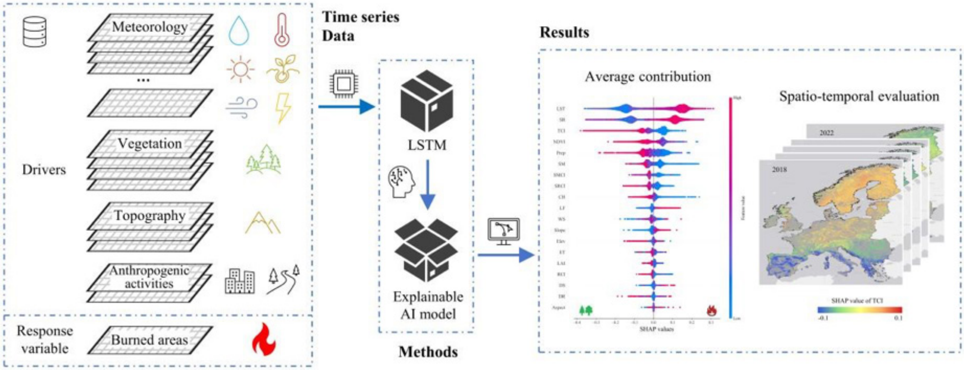
Average contribution. We will compute the average monthly contribution by aggregating the SHAP values of different features within each month. We will also compute the average contribution of each feature by averaging the absolute SHAP values for each sample. This process allows us to obtain an overall overview of monthly and feature contributions.

Spatial evaluation. The SHAP method can be used to explain both known samples and samples that need to be predicted. By discretizing the study area into grid cells, the SHAP method can be used to explain the output of each cell. We will average the results over five years to obtain maps displaying the average contribution for each month. This approach allows us to analyse the spatial differences in the time-lag effect of meteorological and vegetation features across Europe.

Temporal evaluation. By comparing the monthly contributions across different years and integrating historical data, we will further discern the key influencing factors during distinct time periods. We will also conduct a detailed analysis of representative wildfire events to understand how the historical data of various features at different times and locations influences the occurrence of wildfires.

Outlook for the future

In this study, we applied XAI to analyse the spatio-temporal variations of the time-lag effect of meteorological and vegetation features. Using burned area data and time series feature datasets, we developed a reliable wildfire occurrence model with the LSTM method. Wildfire management planners usually have reservations about using machine learning models. However, our work employs XAI methods to interpret the model, opening the ‘black box’ and enhancing the credibility of the model results. In future research, the time series can be extended to analyse long-term impacts of climate change on wildfires. Our work can identify the time lags most relevant for wildfire risk across Europe, which support EU-level management and prevention programs and early-warning systems. Our work also demonstrates that the XAI method has great potential for better understanding the drivers of wildfire risk and provides theoretical support for wildfire prevention and mitigation efforts.



Data processing flow.

Burned Area Detector: a QGIS Plugin for Mapping Burned Areas from Sentinel-2 Images

Thomas Martinoli[1,*], Gloria Bordogna[2], Pietro Alessandro Brivio[2], Piero Fraternali[1], Matteo Sali[2,3], Giovanna Sona[4], Giovanna Venuti[4], Daniela Stroppiana[2]

1 Politecnico di Milano, Dipartimento Di Elettronica, Informazione e Bioingegneria (DEIB), Milano, Italy
2 CNR, Istituto per il Rilevamento Elettromagnetico dell'Ambiente (IREA), Milano, Italy
3 Università degli Studi di Milano Bicocca, Dipartimento di Scienze dell'Ambiente e della Terra (DISAT), Milano, Italy
4 Politecnico di Milano, Dipartimento di Ingegneria Civile e Ambientale (DICA), Milano, Italy

**Corresponding author:* thomas.martinoli@polimi.it

Keywords: multi-spectral images, burned area mapping, burn severity mapping, region growing algorithm, plugin development

Challenge

Wildfires, also known as wildland fires or forest fires, develop where there is available combustible vegetation and an ignition source such as from lightning strikes or human activity. According to NASA, there has been a steady increase in the number of fires: the number of mega-fires (more than 40,500 hectares) increased in the past two decades. A fire that spreads over a wider area, lasts longer, and that develops near an urban area has greater risk and significant consequences for the environment (water, air, and soil pollution) and human health (eye and nose irritation, lung diseases, and cardiovascular diseases). For this reason, it is essential to study, analyse, and understand this phenomenon as much as possible. Data on these events may be collected through Remotely Sensing (RS) data that can be processed by means of a Geographic Information System (GIS) using suitable tools to generate products that can be examined and evaluated. The automatization of the processing algorithms supports large area mapping of wildfires to assess their impacts on the biosphere.

Methodology

In this work we developed a QGIS plugin for detecting burned areas from Copernicus Sentinel-2 MSI pre- and post-fire images. The tool implements algorithms for both burned area mapping and burn severity mapping to produce geo-products depicting the fire-affected areas and the level of damage induced to the vegetation. Both algorithms receive as input multispectral images collected from Sentinel2 (S2) to cover the region of interest before and after wildfire events. The approach to detect burned areas relies on soft computing techniques that integrate features (spectral bands and vegetation indices) derived from S2 images. The integration is carried out using Ordered Weighted Average operators (OWAs) from fuzzy set theory to map burn evidence. The fuzzy pixel-based burned area algorithm is complemented by a region-growing contextual algorithm to balance omission and commission errors. The burn severity algorithm exploits the difference in the Normalized Burn Ratio (dNBR) index in pre- and post-fire S2 images; this step delivers pixel-level classification of the degrees of burn severity. The steps of both the algorithms for burned area and burn severity mapping are implemented in a modular QGIS plugin that provides a user-friendly interface for the management of input data and output products (e.g., spectral indices, burn evidence, burned area maps, burn severity maps). The result of the first algorithm is a binary map where each pixel may assume a value between 0, i.e. "Unburned Area", and 1, i.e. "Burned Area", with intermediate values indicating "partial Burned Area".

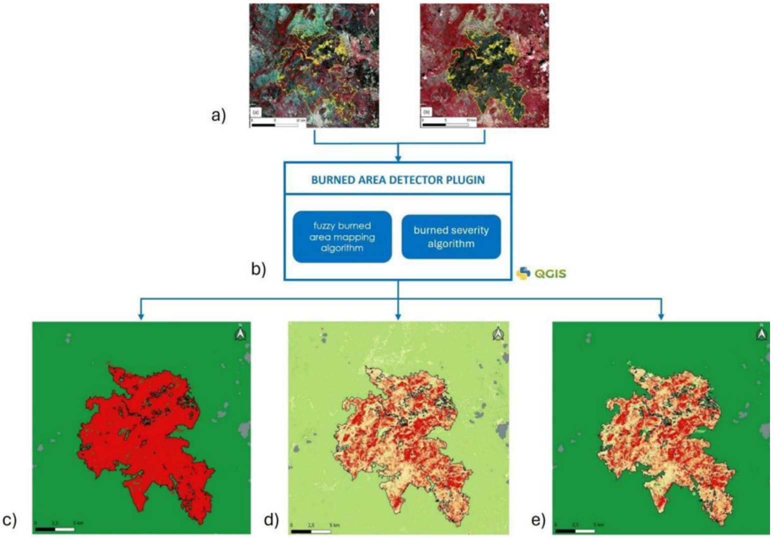
The Burned Area detector (BAD) plugin can be downloaded for free from a public repository in GitHub and installed in QGIS. It was designed and developed to be flexible, letting each user free to choose and use her/his inputs, set the parameters, and choose the features to be integrated to map burned areas. The plugin is implemented in Python programming language.

Expected results

The BAD plug-in was tested over a set of wildfire events occurred in Spain in summer 2022. Pre- and post-fire S2 images were processed with the BAD plugin to derive both burned area and burn severity products for each site. The study sites/events were selected from the activation list of the Copernicus EMS (Emergency Mapping System) Rapid Mapping Activations for Spain 2022. The EMS dataset was used to download fire perimeters and fire damage layers for each event; these layers were compared to burned area and burn severity BAD outputs to assess accuracy of fire perimeters and fire damage.

Outlook for the future

This work in the future will be further extended by expanding its functionalities and by improving its performances. First the plugin could allow the use of input images from other satellite missions providing multi-spectral images such as Landsat missions so as to allow implementing a multi-source approach to burned area mapping. Moreover, the fuzzy burned area mapping algorithm module could be developed to implement flexible and interactive calibration of the parameters to customize the algorithm to the spectral characteristics of the burned area over different geographic areas and ecosystems. Indeed, at present, the algorithm has been tuned and tested over Mediterranean regions. Finally, BAD plugin could enable the user to collect RS data directly from a Web Service to improve automatization also of the preliminary phase, specifically the selection and download of pre and post-fire images of the selected area. For a full implementation of the burned area mapping and assessment workflow, the plugin could foresee also a validation module to produce directly a comparison with reference data.



Synthetic workflow of the BAD plugin applied to a case study in Spain (summer 2022). a) input pre-fire and post-fire S2 false colour composite images with overlaid reference fire perimeters (yellow); b) modules of the burned area and burn severity mapping algorithms; c) burned area map (red=burned, green=unburned), d) severity map (from green unburned to red high severity), and e): combined fire perimeter and burn severity.

LiDAR-based Modelling of the Interaction Between Wildfires and Bark Beetle Outbreak: New Perspective for Italian Forests

Luca Mauri[1,*], **Emanuele Lingua**[1]

1 University of Padova, Department of Land, Environment, Agriculture and Forestry, Legnaro (Padua), Italy

**Corresponding author:* luca.mauri@unipd.it

Keywords: LiDAR, FlamMap, modeling, wildfire, bark beetle

Challenge

Bark beetle outbreaks represent one of the main issues affecting forest stands worldwide. In this context, the storm Vaia occurred in 2018 created an unexpected scenario for Italian Alps, with a subsequent severe spread of bark beetles from the fallen logs to the neighbouring standing forest. In this context, detailed mapping of changes in wildfire behaviour due to bark beetle outbreaks, starting from highresolution LiDAR-based detection of forest fuels, is actually lacking in the scientific community, especially for Italian catchments affected by similar disturbances. This research aims therefore to investigate the role of bark beetles in altering the behaviour of potential wildfires over time, by implementing the FlamMap model considering both the absence and presence of bark beetle damages in a forested catchment (Veneto region, northern Italy). Results could provide more information for stakeholders to identify priority areas for intervention and to implement timely effective solutions to reduce wildfire risk over time.

Methodology

The contribution of bark beetles in altering the behaviour of potential wildfires was first detected by deriving the distribution and characteristics of forest fuels from LiDAR data. Pre-event and post-event scenarios were considered, looking at the absence and successive presence of bark beetles outbreaks in the study area. Raw point clouds were classified and processed in the R environment using specific codes and tools. The spatial distribution of standing forest metrics for both scenarios was extracted by analysing the return pulses and properties of LiDAR data at metric level. Canopy Cover (CC), Canopy Base Height (CBH), standing trees height (CHM) and Canopy Bulk Density (CBD) were extracted, alongside aspect, slope(from the Digital Terrain Models - DTMs), and fuel models. In addition, the spatial inputs required by the empirical FlamMap model to simulate wildfire behaviour were mapped using field data collected in the study area. Potential wildfire propagation and characteristics were therefore simulated in hight-resolution detail, to determine the role of bark beetle outbreaks in altering wildfire characteristics over time. Spatial maps of rate of spread, flame length and fireline intensity were compared between the two scenarios. Statistical analysis further proved such a relationship between bark beetle outbreak and changes in wildfire dynamics at the catchment scale.

Expected results

The proposed workflow for LiDAR data processing highlighted the usefulness of codes and algorithms for implementing automated procedures capable of routinely processing remotely sensed data and deriving specific information on forest properties and characteristics at the landscape scale. The combined use of R-studio and GIS-based tools was proved to be particularly effective for the research purposes. FlamMap results derived from wildfire simulations for the two scenarios enhanced the influence of bark beetle outbreaks on changes in wildfire behaviour over time. Moreover, the use of high-density LiDAR data allowed the computation of fire behaviour maps at the metric level of detail, and notable changes in in RoS, FL and FI were noted when comparing modeling results looking at pre- and post-bark beetle scenarios. The hypothesised correlation between bark beetle proliferation and subsequent changes in wildfire behaviour was supported by statistical analysis. Hypothesis testing and correlation analysis further demonstrated how the presence of bark beetle damages alters the spatial dynamics of potential wildfire affecting forest stands over time. In line with the above, Figure 1 shows the changes detected in the RoS values extracted from the major fire flow paths crossing the study area, before and after the bark beetle outbreak.

Outlook for the future

The proposed methodology for LiDAR data processing enhances the available literature on extracting forest metrics and spatial distribution of tree characteristics at metric level of detail. Future work could specifically focus on the detection of multiple responses of LiDAR data in different scenarios at the individual tree level. The effectiveness of remote sensing data in detecting the influence of natural disturbances in changing standing forest characteristics could be further analysed. Based on the proposed adoption of the FlamMap model and looking to previous researches concerning FlamMap applications in similar landscapes, future research could compare the effectiveness of different empirical models in simulating wildfire behaviour under changing conditions over time, moving to higher resolution of detail. The applied methodology could be further implemented to elaborate a detailed mapping of wildfire risks at the catchment scale and thus defining priority areas to implement preventive silvicultural interventions.

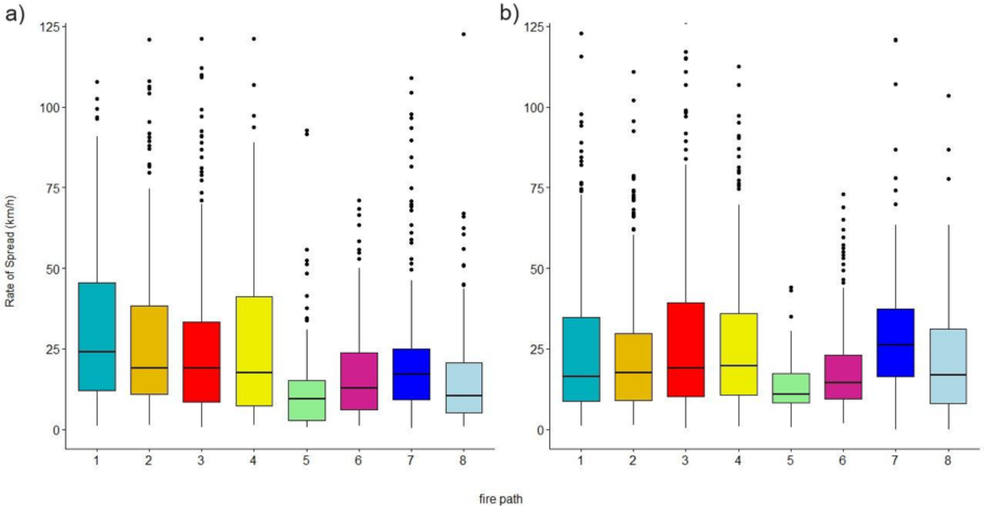


Figure 1. Boxplot showing the differences in RoS values extracted at each wildfire major flow paths as resulted from FlamMap simulations before (a) and after (b) the bark beetle outbreaks affecting the study area.

A Spectral Assessment Framework for Burned Detectability over Peatlands: a Case Study over Marden Moor Fires

Bernardo Mota[1,*], Nicole Reynolds[1], Anna Pustogvar[1]

1 National Physical Laboratory, Climate & Earth Observation, UK

** Corresponding Author:* bernardo.mota@npl.co.uk

Keywords: Earth Observation, spectroscopy, burn area, classification

Challenge

In the UK, it is estimated that heathland, bogland, and grasslands, characterise most of the area burned every year. Peatlands play an important role in carbon storage and represent one of the few natural based solutions to achieve a Net-Zero target. However, most peatlands are degraded and potentially threaten by climate change. It is recognized that the current measuring standard to account for burned area - based on field reporting by emergency services - significantly underestimates the affected area and is not fit for purpose. Earth observation (EO) imagery can play a significant role, but its detectability faces several challenges such as: available cloud free observations, predominance of dark soils, rapid vegetation regrowth, and small size and short duration of fires. This paper aims to better characterize these challenges and identify the spectral separability limits between burn and unburn, and how these change over time.

Methodology

To identify the factors that restrict spectral separability and the associated classification limits, a framework combining a bottom-up with and top-down approach was developed (Figure 1). Applied over the same study region, the two approaches were designed to work independently providing complementary information on the temporal and spatial spectral separability between the burned and unburned. The study site covers an area of 2,255 hectares over Marsden Moor in the South Pennines, characterized as a blanket peat bog, made up of moorland, that frequently is affected by wildfires (Figure 2). In the bottom-up approach, field-based surface spectral measurements were collected during the 2023 fire season over three surface classes - recent burn, old burn and unburned areas - and intra and inter-class variability was characterized, and spectral separability under different class mixture scenarios was evaluated. Class separability is analysed at hyperspectral and multispectral sensor scale, namely, to identify the detectability limits when using the MultiSpetral Imager (MSI). For the top-down approach, time series of Sentinel-2/MSI L2A reflectance retrievals covering area are used to characterize intra and interclass variability, and spectral separability is temporally assessed, to identify how long separability is restored to its pre-fire levels. Results for both approaches are then translated into classification errors, providing an indication on the mapping accuracy limits.

Expected results

Preliminary results not only show agreement between the different approaches but also complementary information. For the Bottom-up approach the spectral signature characterization shows that there is large intra and inter-class variability between new and old burn and unburn, limiting spectral separability under certain class mixture scenarios. In addition, separability is significantly restricted when using the SWIR-2 spectral region (2000-2300 nm), and that the best separability wavelengths are in the NIR, but the optimal separability is found over the IR-2 region (1200-1300 nm), namely over the soil water absorption range. For the top-down approach, the results also show large intra and inter-class spectral variability, and that these are highly temporally dependent. Meaning that, on average, initial post-fire separability is reduced to pre-fire levels after three months, significantly affecting the ability to capture the full extent of a burn scar when using Sentinel-2/MSI imagery. In addition, the results also show that the best classification solution (single, multi or in spectral indexes) needs to account for the changes captured in NIR band. All results were analysed in the context of their propagated uncertainties, and limiting mixing scenarios examples, and downstream classification errors will be presented.

Outlook for the future

In this presentation, we proposed framework to assess the detectability limits of burn areas over peatlands using EO retrievals. The framework is based on two approaches that combined show how class spectral separability is dependent on class mixture, at spatial and temporal scales. Results are easily translated into classification error and can be used to define criteria for an operational BA detection program over the UK peatlands.

In particular, the framework aims providing algorithm developers the information on what are the favourable conditions, and the associated classification error that can be propagated to downstream products, such as to account for GHG emission from biomass burning. This analysis also provides important information for the applicability of, current and planned, hyperspectral-based satellite missions and how these could play a crucial role in monitoring vegetation condition.

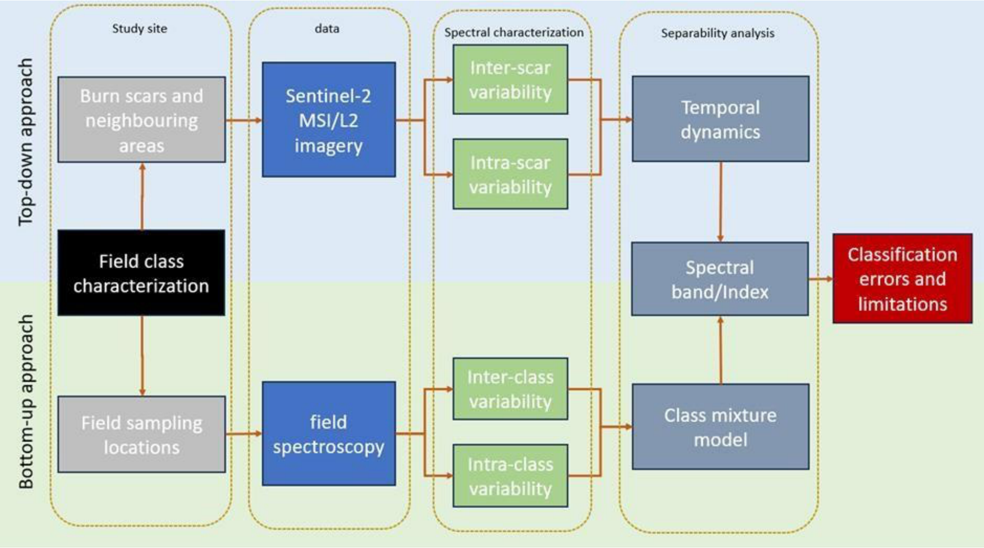


Figure 1. Spectral separability assessment framework.

Figure 2. Surface heterogeneity of a burned peatland scar over the Marden Moor area as the results of the Haigh Clough fire on the 9th April 2023.

Burnt Area Monitoring in Near-real Time Combining high Spatial and Temporal Resolution

Michael Nolde[1,*], Moritz Rösch[1], Torsten Riedlinger[1]

1 German Aerospace Center (DLR), German Remote Sensing Data Center (DFD), Germany

**Corresponding author:* michael.nolde@dlr.de

Keywords: burnt area analysis, fire monitoring, near-real time, hyperspectral data, enmap

Challenge

Devastating fire events in Europe (e.g. Greece 2023, Spain 2022) but also on a global scale (e.g. Chile 2024, see example below, Canada 2023) show the importance to mitigate wildfire spreading as early as possible. This implies the availability of timely, accurate and robust information. The Center for Satellite-based Crisis Information (ZKI) Wildfire Monitoring System, operated at the German Aerospace Center (DLR), is a research platform providing satellite-derived burnt area information for Europe and North Africa. The information is provided in near-real time whenever new satellite overpasses are available. In order to provide the highest possible update frequency, the system supports a multitude of input sensors. While the system is primarily based on mid-resolution data, latest developments have been focussing on enhancing the results with higher-resolution data as soon as these data become available. This includes the DLR sensors DESIS and EnMap, the first two hyperspectral sources utilized by the system. However, since the sensors feature 235 and 222 spectral bands, respectively, efforts have been undertaken to define which bands yield the highest benefit for burnt area analysis.

Methodology

As a preceding step, we prepared a geospatial footprint for each archived DESIS and EnMAP acquisition from textual metadata. Then, we merged each footprint with NASA FIRMS active fire information intersecting the footprint and occurring within two weeks before the scene acquisition. The combined active fire area is then set in relation to the footprint area, which allows for a ranking of archived DESIS / EnMAP scenes by contained fire activity. In a following step, we ordered all scenes which were found to feature more than 5% fire activity from the DLR EOWEB data portal. Since the near-infrared (NIR) domain is well known to yield the highest benefit for the task of burnt area derivation (due to its chlorophyll-dependent characteristics), we performed a brute-force approach by analyzing each NIR band (103 and 29, respectively) of each selected DESIS/EnMAP scene with the burnt area methodology used by the ZKI Fire Monitoring system. Each result was compared against a reference from the NASA MCD64A1 burnt area dataset and evaluated by means of the Jaccard Index (IoU). The results are attributed with the mean Fire Radiative Power (FRP) of the active fire data, to obtain information about fire intensity together with the burnt area perimeter. For the final result, area-weighted mean IoU values were determined for each bandwidth in order to identify the bands with the highest suitability for burnt area derivation.

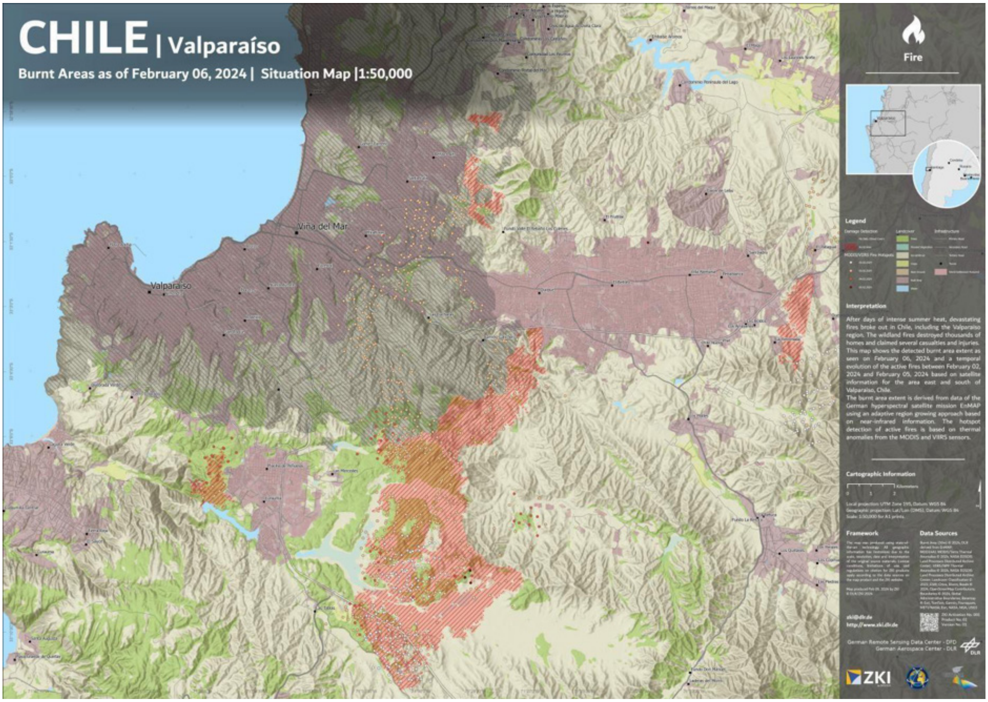
Expected results

Early results indicate that the optimal NIR wavelength for burnt area derivation is located around 820 nm for burnings with average FRP. However, this value is dependent on various factors, such as the intensity of the actual burning. This is interlinked with the affected vegetation type and its health status, amongst others. The study determines a set of optimal wavelengths for burnt area derivation in relation to identified factors such as fire intensity, affected land cover type and vegetation health. The results represent valuable information for hyperspectral burnt area mapping, and can be considered a solid base for an automated analysis process. The findings are not only applicable for the DESIS and EnMAP sensors used in this study, but to all hyperspectral sensors featuring bands in the NIR domain. Besides supporting wildfire related studies, the identified wavelengths represent valuable information in the field of sensor development. Instruments targeted at wildfire detection and analysis can thus be designed in an optimized way. This work is one of the first broad-scale hyperspectral wildfire analysis studies available und illustrates the suitability of hyperspectral data for wildfire-related research in the future.

Outlook for the future

The results indicate that there is no single optimal wavelength to be chosen. Rather, the input band should be selected in accordance with the fire intensity present in a given scene. Optimized results could be achieved, when the input band is chosen for each burnt region individually. Further developments of the platform will presumably support the analysis of active fire FRP values in a pre-processing step, selecting the most suited band or band combination for the analysis of specific sub-regions of the scene.

(A) Example burnt area derived from EnMAP data for a devastating fire near Valparaíso / Chile, Feb. 2024.



After days of intense summer heat, devastating fires broke out in Chile, including the Valparaíso region. The wildland fires destroyed thousands of homes and claimed several casualties and injuries. This map shows the detected burnt area extent as seen on February 06, 2024 and a temporal evolution of the active fires between February 02, 2024 and February 05, 2024 based on satellite information for the area east and south of Valparaíso, Chile.

The burnt area extent is derived from data of the German hyperspectral satellite mission EnMAP using an adaptive region growing approach based on near-infrared information. The hotspot detection of active fires is based on thermal anomalies from the MODIS and VIIRS sensors.

Local projection: UTM Zone 19S, Datum: WGS 84
Geographic projection: Lat/Lon (DMS), Datum: WGS 84
Scale: 1:50,000 for A1 prints.

The Struggle to Combine Various Remote Sensing Data into Input Layers for a Fire Modelling System – Example from the Czech Republic

Jan Novotný[1,*], Markéta Poděbradská[1,2], Lucie Kudláčková[1,2], Miroslav Pikl[1], Emil Cienciala[1,3], Jana Beranová[3], Miroslav Trnka[1,2]

1 *Global Change Research Institute of the Czech Academy of Sciences, Brno, Czech Republic*
2 *Institute of Agrosystems and Bioclimatology, Mendel University in Brno, Brno, Czech Republic*
3 *IFER, Institute of Forest Ecosystem Research, Ltd., Jílové u Prahy, Czech Republic*

**Corresponding author:* novotny.j@czechglobe.cz

Keywords: wildfire, Czech Republic, FlamMap, modelling, remote sensing

Challenge

In the Czech Republic, traditionally low wildfire risks attributable to its geography, climate, and landscape are shifting. Climate change is introducing more extreme weather conditions, making Central Europe, including the Czech Republic, increasingly susceptible to wildfires. This trend is evidenced by a growing frequency of fires over the past decade. At the end of July 2022, the largest recorded wildfire broke out in the Bohemian Switzerland National Park (BSNP), with a burned area of around 1000 hectares. This event, unprecedented in the Czech context, has spurred interest in wildfire modelling beyond the scientific community. Our team of co-authors has been studying fire behaviour models under Central European conditions for several years. The current challenge is to compile datasets available for the whole Czech Republic and methodology for translating them into input layers for a fire modelling system. That will enable rapid analysis of fire events, active fire simulations, early warning and interventions.

Methodology

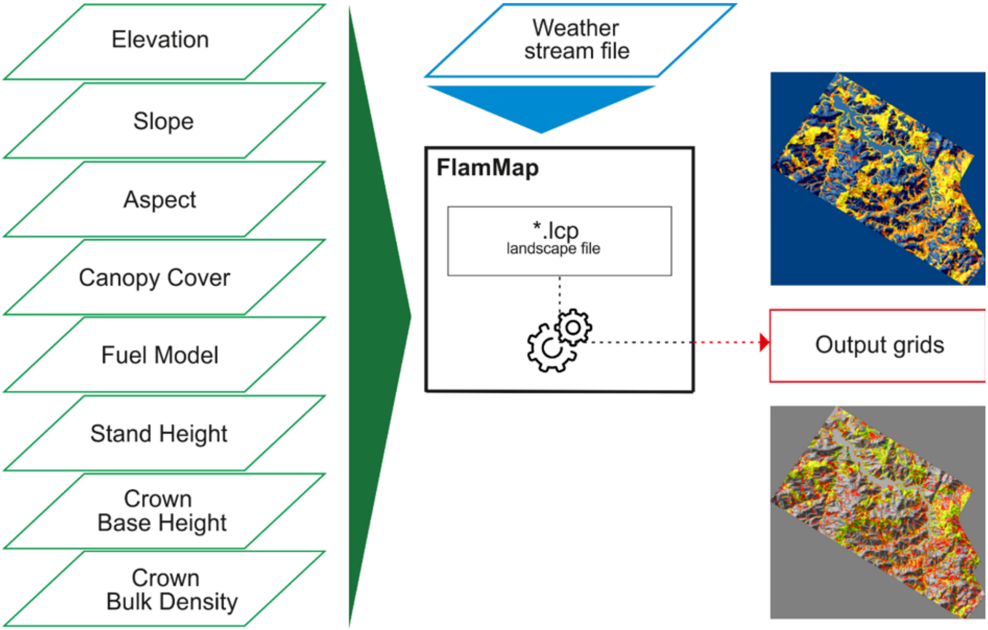
We use the FlamMap modelling system developed at the Missoula Fire Sciences Laboratory (USA). FlamMap requires eight geospatial data themes describing the fuels – fire behaviour fuel model (FBFM), canopy cover (CC), stand height (STH), crown base height (CBH), and canopy bulk density (CBD) – and topography (elevation, slope and aspect) across a given area. The other input data requirements –including information on dead and live fuel moisture levels, hourly meteorological data (temperature, precipitation, relative humidity, and cloudiness), and wind speed and direction – are outside the scope of this contribution. The main source of information about forest canopies for local studies – such as BSNP fire – is airborne laser scanning. On the national level, such detailed data are unavailable. To address this, we utilize a digital terrain model from the State Administration of Land Surveying and Cadastre for topographical data, while forest height data (normalised digital surface model) from the governmental Forest Management Institute helps us derive CC and STH values. CBH and CBD are estimated using empirical models calibrated using National Forest Inventory field data. FBFM values are based on various layers describing vegetation age, dominant species, stand density, and site fire risk index. The fuel models for the non-forested areas are assessed using information obtained from the Czech Land Parcel Identification System, digital hydrological data, Open Street Maps, CORINE 2018 land cover map, and other sources. The overarching challenge lies in synthesizing this diverse data into a cohesive landscape file suitable for FlamMap.

Expected results

The results of the study on the BSNP fire are presented in the paper by Kudláčková et. al., 2024 (doi.org/10.1007/s11069-023-06361-8). The aim of this contribution is to report our steps further from the local level to the national level fire modelling. We will present the data sources and the workflow for each of the eight components of the FlamMap Landscape file. We will comment on the differences between local scale approach and national level approach. Impact on modelling results from FlamMap simulations will be analyzed.

Outlook for the future

This contribution is centred around remote sensing data sources and the methodology of their assimilation into a FlamMap landscape file. The overall aim of our work is to combine remote sensing expertise with climate/weather monitoring and forecasting and with the expertise on forest management to provide Fire Rescue Service of the Czech Republic with reliable early warning information. When finalized and tested, we believe that the methodology may be expanded across the administrative borders to the broader (Central) European context.



Graphical abstract of the FlamMap modelling system. How to prepare the 8 input layers on the left from remote sensing data is the main topic of this contribution.

A Remote Sensing-based Scalable Decision Support System for Assessing Forest Wildfire Vulnerability: Mont Avic Natural Park case in Aosta Valley (Italy)

Tommaso Orusa[1,2,*], Samuele De Petris[2], Filippo Sarvia[2], Alessandro Farbo[2], Duke Cammareri[1], Davide Freppaz[1], Enrico Borgogno-Mondino[2]

1 IN.VA spa & Earth Observation Valle d'Aosta, GIS Unit, Brissogne, Italy
2 University of Turin, Department of Agricultural, Forest and Food Sciences (DISAFA), GEO4Agri DISAFA Lab, Grugliasco, Italy

**Corresponding author:* torusa@invallee.it

Keywords: earth observation data, vertical biomass, support decision system, forest fire prevention, Aosta Valley - Mont Avic

Challenge

Nowadays, GIS and Remote Sensing play a crucial role in supporting Forest Planning and Management (FPM), particularly in assessing forest wildfire vulnerability and associated risks. While several services, ranging from pan-European to global mapping, are already available, few incorporate vertical biomass assessment, model vegetation drought trends, or evaluate ecosystem service values. Additionally, the integration of mountain paths and foot traffic mapping concerning population risks in case of forest fires remains underutilized in transferring risk analysis technology to the forestry sector, despite the potential synergies between civil protection and FPM. Climate change is exacerbating the frequency and duration of drought episodes, placing greater stress on vegetation and increasing the vulnerability. This aspect is compounded also by poor management or abandonment in many wood areas of Italy therefore geomatics-based products to support adaptive FPM strategies are necessary.

Methodology

The study focused on Mont Avic Natural Park in the Autonomous Aosta Valley Region (NW Italy). Specifically, the approach is based on vertical biomass (VB) assessment, drought trends modelling (DT) and forest ecosystem services values mapping (FESV). In this case the biomass layer was obtained from a 0.5m resolution Canopy Height Model (CHM) from the 2020-2021 lidar aerial flight to segment canopies via local-maxima algorithm and calculate species-specific incidence areas and related diameters.

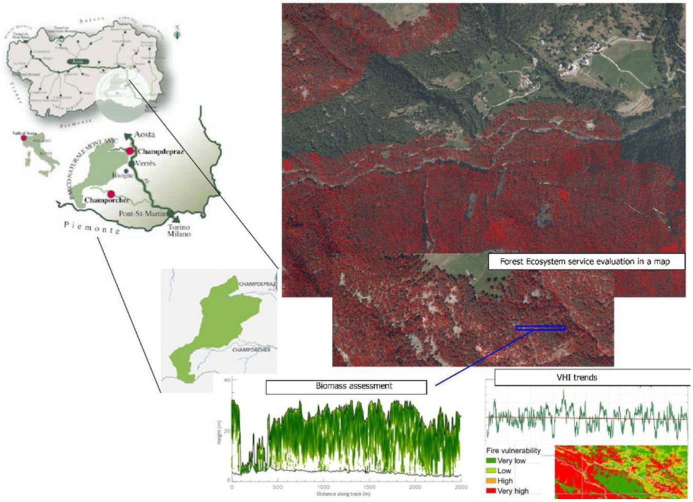
Dendrometrics formulas were applied to estimate volume and validation performed with ground measure data. To assess droughts the Vegetation Health Index (VHI) trends were computed and modelled by using a first polynomial order equation from Landsat missions 4 to 9 within Google Earth Engine. It is worth noting that clouds, shadows and defective pixels were masked out. Moreover, VHI composites were mapped within May to November (the most vulnerable period to wildfire) per each year. Then, FESV were accounted and mapped from Aosta Valley Land cover and Forest types layer both available at SCT Regional Geoportal. FESV values were retrieved from the existing scientific literature. Finally, upon these normalized layers an ISODATA clustering was performed to identified ecologically similar areas, defining ecological vulnerability and intervention priority classes based on higher values of VB tenure, DT gains, and FESV.

Expected results

A scalable decision support system for assessing forest wildfire vulnerability has been developed using Remote Sensing techniques. In Mont Avic Park, a mapping effort primarily relying on geomatics techniques was undertaken to understand forest dynamics and vulnerabilities, facilitating targeted management interventions. This approach involves mapping biomass distribution, analysing drought trends, and evaluating ecosystem values, thereby enabling the prioritization of interventions in ecologically sensitive areas. Additionally, a preliminary population risk analysis was conducted by mapping areas at greater ecological risk, including proximity analysis to neighbouring mountain paths and incorporating the average degree of foot traffic using data from the Lifesight foot traffic dataset. The scalability of this approach allows for adaptation to various landscapes, extending its applicability beyond parks to diverse regions. In instances where updated Canopy Height Models (CHM) are unavailable, vertical biomass can be derived through radar missions and interferometric or tomographic processing. Through cluster analysis and trail assessment, ecologically similar areas and high-risk zones have been identified, providing valuable insights for strategic FMP decisions.

Outlook for the future

In future developments, integrating necromass through ground surveys or forest modelling techniques could certainly enhance the proposed approach. While this system offers scalability and adaptability, challenges such as data availability and processing complexity persist. Incorporating emerging technologies and fostering interdisciplinary collaboration could strengthen the robustness and applicability of this methodology. Future efforts should prioritize refining spatial forest datasets and increasing awareness of advancements in Geospatial technologies, including Graph-based Deep Learning or evolutionary algorithms. Consequently, the adoption of PNRR funds for a national Canopy Height Model (CHM) at 0.20 m resolution would be a significant milestone in supporting forest inventories and wildfire management and planning by providing updated vertical biomass knowledge. Additionally, the future IRIDE



Graphical abstract.

Change Detection Approaches with Synthetic Aperture Radar Images: Random Forests and Sentinel-1 Observations for Burned Areas Mapping

Pietro Mastro[1], **Antonio Pepe**[1,*]

1 CNR, Istituto per il Rilevamento Elettromagnetico dell'Ambiente (IREA), Neaples, Italy

**Corresponding author:* pepe.a@irea.cnr.it

Keywords: earth observation, change detection, flood, fire, Copernicus

Challenge

Inspecting the time series of backscattered radar echoes collected by the twin Sentinel-1A-B (S-1) synthetic aperture radar (SAR) sensors, we developed a method to identify the extent and the impact on the ground of changes occurring after a disastrous event. This methodology makes use of some coherent and incoherent SAR change detection indices (CDIs) and their mutual interactions in a single framework to produce rapid mapping of surface changes. Specifically, we identified and test the capability of some CDIs that could synthetically describe ground surface changes associated with a disaster event (i.e., the pre-, cross-, and post-disaster phases), based on the generation of sigma naught and the interferometric SAR (InSAR) coherence maps. Then, we trained a random forest (RF) to produce CD maps and studied the impact on the final binary decision (changed/unchanged) of the different layers that represent the available CDIs. The experiments were successfully carried out considering areas subjected to wildfires and extreme weather conditions (e.g., flooded regions) and by evaluating the impact of these events on the ground.

Methodology

Remote Sensing technologies play a crucial role in detecting and monitoring ground surface changes through the analysis of multi-temporal, remotely sensed images [1]-[2]. While optical RS sensors have largely been exploited for change detection (CD) analyses and for diverse applications, the potential of SAR images in CD has remained less explored. SAR images offer operational advantages as active sensors capable of operating in any atmospheric and sunlight conditions. The availability of SAR data from constellations like Copernicus Sentinel-1A/B nowadays permit the rapid mapping of Earth's surface changes, helping risk assessment and disaster risk management in areas prone to geohydrological and climate-change induced disasters. Furthermore, advances in RS technology [3]-[4] facilitated the generation of rapid damage prediction maps, e.g., through services like the Copernicus Emergency Management Service (EMS) (https://emergency.copernicus.eu/). Change Detection is a well-consolidated process that analyzes two or more images captured over the same geographical area at different times and is capable of identifying those significant land cover changes that have meanwhile occurred. This process may be modelled as a binary classification problem where each pixel is mapped into the set of possible labels related to the classes of unchanged and changed pixels. In this general context, the use of AI methodology (e.g. Random Forest) helps testing the changed/unchanged hypotheses.

Expected results

We jointly use the amplitude and phase information embedded in a time series of SAR data in an area where some significant changes occurred. Accordingly, we exploited a set of coherent and incoherent Change Detection indices (e.g., the mean sigma naught VH and VV maps, the sum/difference of co-pol sigma naught maps, the coherence ratio, etc.) and tested the validity of these indices in a real context. Some results have already been shown in [5]. Here, we would like to stress the functioning of the implemented AI-driven approach for CD considering the case of a severe wildfire. The general idea is to consider sets of SAR images before and after the occurrence of a main event (e.g., Figure 1 shows an example of InSAR coherence maps computed across and before an event). The combined use of InSAR and amplitude information has revealed suitable for the rapid mapping of changed areas. Figure 2 shows the maps of changed areas obtained by applying a Random Forest change detection methodology fully detailed in [5] referring to two fire events occurred in summer 2021 over Sardinia and Sicily islands. The spatial comparison with products from EFFIS system shows the ability of the proposed method in correctly identifying the burned areas. It highlights the goodness of RF-oriented solution.

Outlook for the future

As a further development, we intend to extend our research on change detection considering sets of heterogeneous optical and radar images. The inclusion of optical features and the fusion with the SAR data into one RF forest classifier is expected to improve the generalization performance (e.g., in flooded areas). Fine tuning and extensive exploitation of the proposed method on a large spatial/temporal scale would also require the selection and processing of several independent SAR datasets and the selection of a heterogeneous family of potential disasters (e.g., flood, drought, extreme events, forest and vegetation disturbance, urban changes, earthquakes, volcano eruptions, man-made changes, etc.). This perspective is worthwhile and represents an open issue for further in-depth investigations.

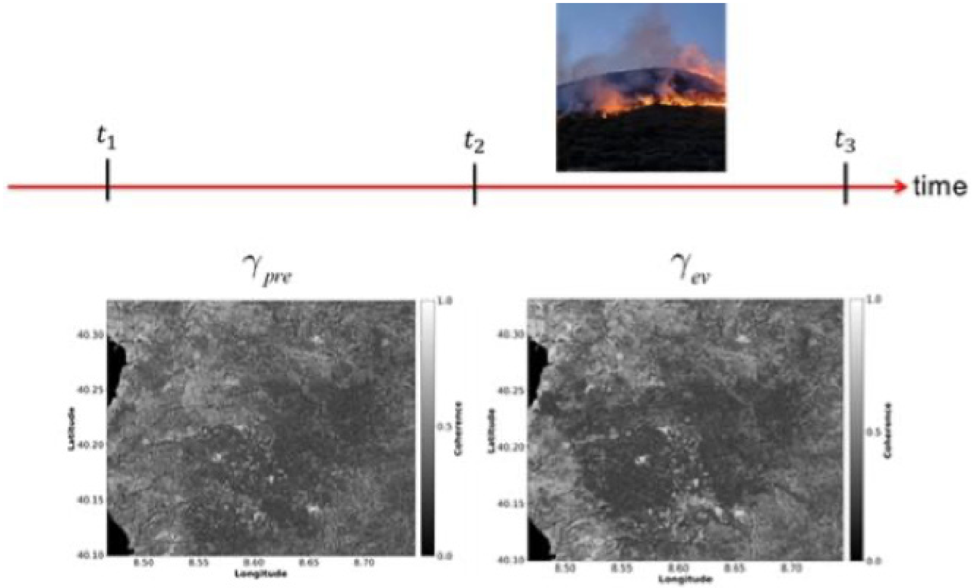


Figure 1. Coherence change tracking scheme using two SAR images acquired before and after an event (e.g.. a fire) responsible for a detectable ground change. An example of the coherence maps related to Montiferru Sardinia fire of August 2021.

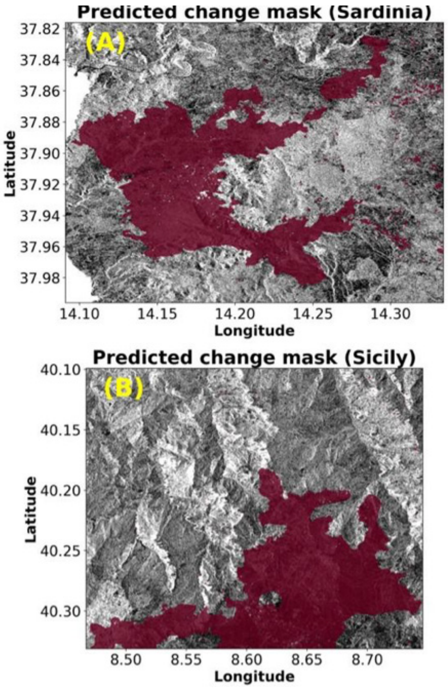


Figure 2. (A) Random Forest predicted changed areas mask (A) 2021 Montiferru fire in Sardinia and (B) 2021 Sicilian Madonie Apennines fire.

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Statistical Evaluation of the Impact of Wildfires on Forest Habitats using Earth Observation data and Machine Learning

E. Agrillo[1], F. Filipponi[2], R. Inghilesi[1], A. Mercatini[1], A. Pezzarossa[1,*], N. Tartaglione[1]

1 Italian Institute for Environmental Protection and Research, Italy
2 CNR, Istituto di Geologia Ambientale e Geoingegneria (IGAG), Rome, Italy

**Corresponding author:* alice.pezzarossa@isprambiente.it

Keywords: earth observation, wildfires, forest mapping, monitoring, land management

Challenge

Wildfires constitute a threat to both environment and human activities. Furthermore, they represent one of the major disturbances to biodiversity and its natural capital. The accurate identification and post-fire monitoring of burned areas in forest habitats is therefore important for research and institutions to implement effective restoration policies. ISPRA, as the Italian National Environmental Agency, has developed an environmental surveillance and classification system based on Earth Observation data, aimed at the assessment and post-fire monitoring of forest habitat affected by wildfires. Wildfires' burned areas are identified and classified in a geo-spatial database in order to allow a real time monitoring of the impact of fires on forest habitat, as well as the statistical analysis at different spatial scales. This will hopefully support policies dedicated to the ecological recovery of damaged ecosystems over time.

Methodology

To analyse the impact of wildfires on forest habitats, both the geo-located polygons identified by the Copernicus European Forest Fires Information Systems (EFFIS) and a forest habitat distribution map have been used. The latter is obtained from a classification model realized by ISPRA applied in the Lazio region, in central Italy. The labels used in the model to define the targets of the supervised classification procedure are the classes of forest habitats defined in Annex I Directive 92/43/EEC. About 4000 habitat observations have been extracted and labelled from a vegetation-plots regional database and field surveys. The result of the labelling is the set of targets used to train the classification model. A large set of data have been used to organize the prediction variables, comprehensive of several environmental predictors and Sentinel-2 MSI satellite data acquired during year 2022. A random forest classification model has been applied to the learning part of the dataset, and the resulting model has been tested on a separated set of data. The prediction, in terms of the different classes at the spatial resolution of 20 m has been applied to the forest mask generated from the Copernicus Land Cover Plus Backbone classification product. The Lazio forest map has been employed to estimate the amount of the different forest habitats present in all the EFFIS burned areas in Lazio from 2019 to 2023. Spatial statistics are evaluated at every administrative level and also in protected areas.

Expected results

The calibrated random forest model allowed the identification of 13 different classes of natural forest habitats and one class of afforestation with coniferous trees (Figure 1, panel A). The classification results show a good confidence, in terms of forests habitat being correctly predicted. The overall accuracy is almost 70% and half of the classes detected have both “User’s and Producer’s” accuracy higher than 60%. Some of the results have also been verified by field validation. The model classified almost 400 000 hectares (ha) of forest habitats in the Lazio region, represented mostly by deciduous oak forests – habitat code 91M0 (33%) and 91AA (10%), evergreen oak forests - habitat code 9340 (20%), and beech forests - habitat code 9210 (17%). In the period 2019-2023 the forest habitats affected by wildfires in Lazio were largely represented by the evergreen oak forests - habitat code 9340, and the deciduous oak forest - habitats code 91M0 and 91AA. All these habitats are mainly distributed in the southern part of Lazio (Figure 1, panel B). Moreover, the woodland classes more affected by wildfires are within coastal and sub-mountain belts. The time series analysis of regional data shows that the year 2021 has been the worst year, with almost 2925 ha of forest habitats affected by wildfires. The year 2022 (2157 ha) was only slightly better, while in 2020 the amount of forest habitats affected by wildfires was 1523 ha, in 2023 was 1023 ha and finally the 2019 was 518 ha.

Outlook for the future

The approach presented here demonstrates the importance of information technology methods to support local institutions and Forest Corps in the vegetation assessment of post-fire events.

These procedures are also valuable to define new best practices for future restoration of forest habitats and their ecosystem services, especially inside protected areas (e.g. see the case of the Regional Nature Reserve of Mount Catillo shown in Figure 2). A high-resolution map of forest habitat distribution and the identification of the main forest categories affected by wildfires could be the primary thematic information useful for generating fire susceptibility mapping, aimed at prioritizing specific preventive actions. The results obtained could also be useful for the detection of forest habitat changes in space and time. Evaluating the impact

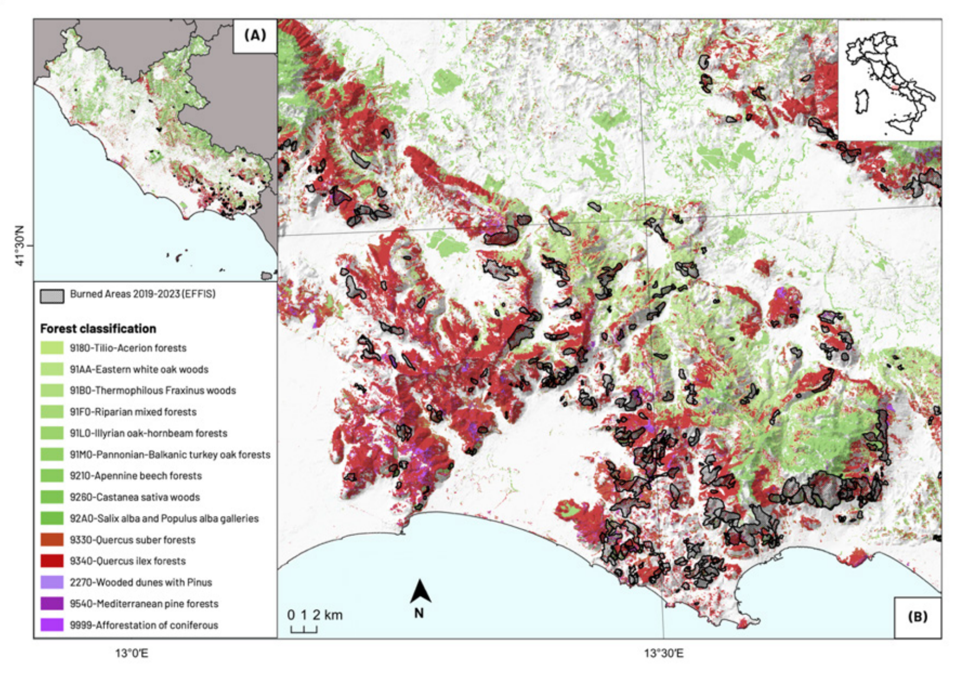


Figure 1. Forest habitat map of Lazio region in central Italy from Random Forests model at habitat directive 92/43/EEC legend and burned areas since 2019 form the EFFIS database (panel A) and the details of the most affected areas in southern Lazio (panel B).

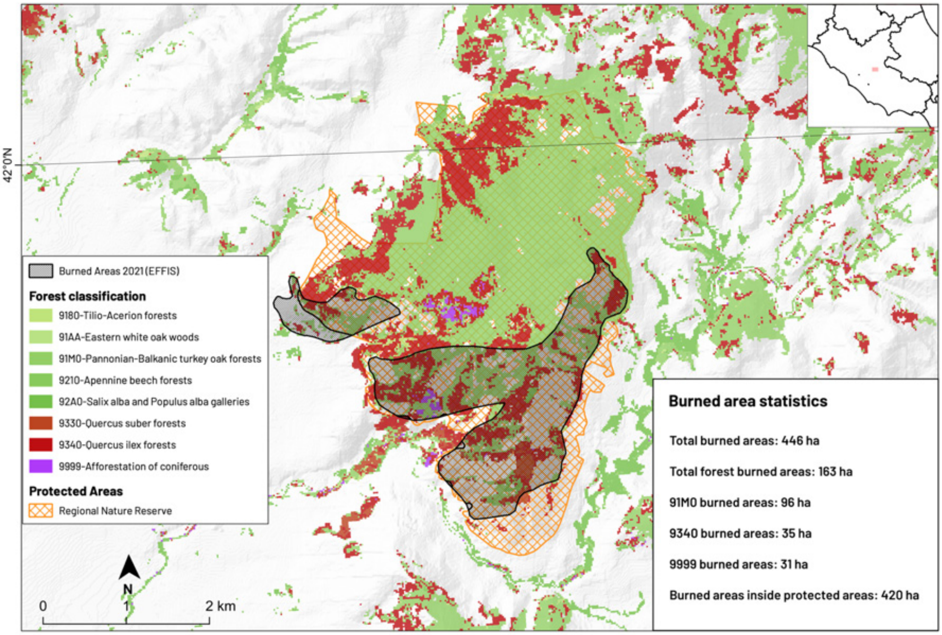


Figure 2. Statistics on the burnt areas in the 2021 summer wildfires near and within the Regional Nature Reserve of Mount Catillo (Tivoli, Rome).

The PM2.5 Pollution from Biomass Burning in Galicia 2022

Cesar Quishpe[1,*], Patricia Oliva[1]

1 Alcalá University, Department of Geology, Geography, and Environment, Spain

**Corresponding author:* cesar.quishpe@uah.es

Keywords: pollution, PM2.5, wildfires, CAMS

Challenge

The deterioration of air quality due to increased biomass burning is a growing concern in Galicia. This fire-prone region faces health care challenges for its inhabitants. Our study aims to estimate the impact of forest fires on PM2.5 levels during the summer of 2022. We employed a Lagrangian framework for particle dispersion modeling to assess this impact, detecting concentration levels in Galicia. Air quality stations in populous cities like Vigo, Ourense, Santiago de Compostela, Lugo, and Pontevedra were utilized. Results show biomass burning directly affects air quality, surpassing WHO PM2.5 pollution guidelines. Regional burns, including those outside the region, significantly contribute to pollution, emphasizing the regional impact on Galicia. Effective mitigation measures are imperative to preserve air quality and public health.

Methodology

This study is based on the Lagrangian method as a tracer to identify and track pollution columns, revealing their characteristics (Casallas et al., 2024). We used data from the VIIRS sensor (Visible Infrared Imaging Radiometer Suite) to identify the number of forest fires with high precision for the fire events of 2022 occurred in the Northwest region of the Iberian Peninsula. We also used the CAMS (Copernicus Atmosphere Monitoring Service) air quality forecast for Europe database to extract PM2.5 particulate matter concentrations at a spatial resolution of 0.1 degrees (approximately 10 km). To check the estimations provided by CAMS, we used the time series of six ground air quality stations from Meteogalicia. The application of the Lagrangian method begins by segmenting the image, this process identifies unique objects based on distinctive characteristics. Then, we apply a threshold to label objects that exceed certain predefined or dynamically adjustable values. We then track these objects to calculate their trajectories and determine the evolution of the smoke plumes. This approach enhances our understanding of pollution dynamics and its impact on air quality in Galicia. The tracker assigns labels in the first time step, and follows intervals of one hour for the CAMS data. Subsequently, it uses Euclidean distance and object (fire event) overlap to decide if an object is new or if it is the same as a previous one, maintaining the label. Thus, the algorithm tracks the evolution of the pollution column, facilitating the analysis of its characteristics. This method nables fully relating sources to impacts on cities, quantifying the volume of pollution transported from critical emission points. Thus, we assess to what extent the increase in pollution in Galicia is due to related emission sources. Finally, the process of identifying and characterizing hazardous events of PM2.5 pollution is based on international guidelines from the World Health Organization (WHO) and air quality regulations in Spain. Which state that annual average concentrations of PM2.5 should not exceed 15 µg/m3 for more than 3 to 4 days per year. In this sense, we have selected three events that occurred in the summer of 2022 that maintain high concentration levels as an example of the application of this method (Figure 1).

Expected Results

The spatial-temporal distribution of forest fires showed that in June, fire events were detected outsid Galicia, suggesting a possible influence of external factors at this time of year. However, in July and August, there was a combination of events both inside and outside Galicia, with July being the month with the highest fire activity, corroborating similar findings in previous research (Rodrigues et al., 2023). The activity of forest fires in July led to a significant emission of pollutants, as evidenced by PM2.5 concentration measurements, shown in the second column of section (b) of Figure 1. A clear pattern of dispersion of these pollutants throughout the region is observed, especially during July when several days of fires significantly affected air quality in Galicia, surpassing the limits set by the WHO for PM2.5 pollution. It is important to note that most cities in Galicia experienced high levels of air pollution during these forest fire events, with the notable exception of La Coruña, located at the northern end of the region. This difference in exposure is probably attributed to the city’s geographical location and predominant wind patterns. The results also show that, in the absence of forest fires, pollution levels decreased significantly, remaining at lower values between 10-15 µg/m^3, as shown in the third column (c) of Figure 1. This highlights the direct impact of forest fires on the region's air quality. Finally, when analyzing the time series of ground stations, we observed a consistent pattern of increased pollution concentration during forest fire events, confirming the effectiveness of the Lagrangian framework used in our study to track the evolution of atmospheric pollution. The observations in Figure 1d are consistent with the results obtained and provide additional validation of our methodological approach.

Outlook for the Future

These results show the significant impact of forest fires on PM2.5 atmospheric pollution in Galicia. While the framework is capable of demonstrating the relationship between forest fires and high pollution episodes in some cities in Galicia, as well as quantifying the amount of pollutants reaching these areas, there are still aspects that require improvement. For example, considering turbulence within objects could be a potential source of error. Likewise, the thresholds used within the model may generate uncertainties, so other filters must be incorporated to avoid capturing small or short duration events not associated with forest fires. Additionally, further research is required to address the dynamics of other pollutants and their interaction. Prolonged exposure to high levels of PM2.5 and other pollutants poses a significant risk to public health, emphasizing the urgency of implementing preventive measures and air pollution management in the region. It is essential to develop early warning methods for large-scale events and improve forest fire management strategies to mitigate their impact on air quality in Galician cities.

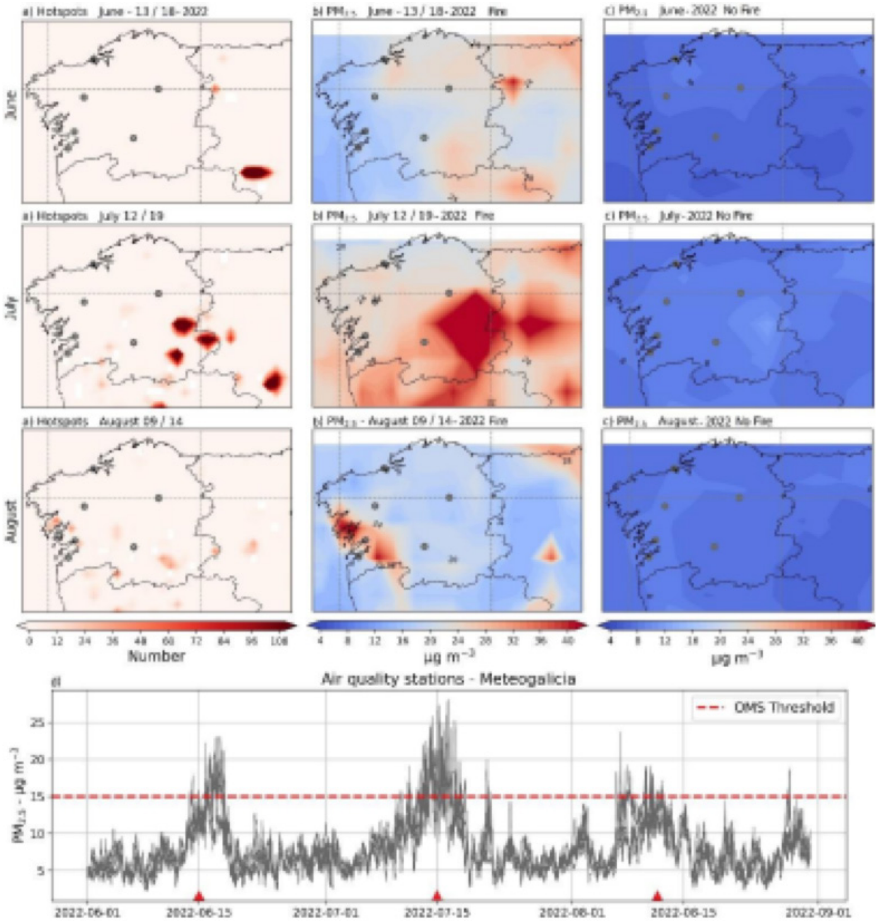


Figure 1. The first column (a) shows the active forest fire spots detected by the VIIRS platform on dates with the highest incidence of fires during the months of June, July, and August. The maps of the average concentration of PM2.5 for similar dates, where colors indicate the magnitude of atmospheric pollution, as illustrated in column (b). In the third column (c), the monthly average concentration of PM2.5, excluding days with forest fires, is shown. The time series of air quality stations located in the most populous cities of Galicia, during the period from June to August 2022, are presented in section (d).

Extreme Climate Hazards Determining Fire Severity in Woodlands: a GeoAI Approach

Zeinab Shirvani[1,*], **Yifang Ban**[1]

1 KTH Royal Institute of Technology, Department of Urban Planning and Environment, Sweden

**Corresponding author:* zeinabsh@kth.se

Keywords: extreme climate hazards, fire severity, GeoAI, TerraClimate, woodlands

Challenge

The resilience of tropical woodlands and dry forests is increasingly compromised by forest fires, which are triggered by extreme climate hazards, leading to significant losses of both aboveground and belowground biomass. While there has been progress in mapping fire severity, understanding the climatic extremes that influence fire severity levels remains a substantial challenge, particularly in regions like tropical woodlands where the sparse network of climate gauges limits comprehensive climate monitoring. The integration of remote sensing for both extreme climate events and forest fires, along with advancements in geospatial artificial intelligence (GeoAI), offers a promising avenue to overcome these obstacles. By leveraging GeoAI data and methodologies, this study aims to illuminate the complex interplay between climate extremes and forest fire dynamics within the miombo ecoregion, southern Africa.

Methodology

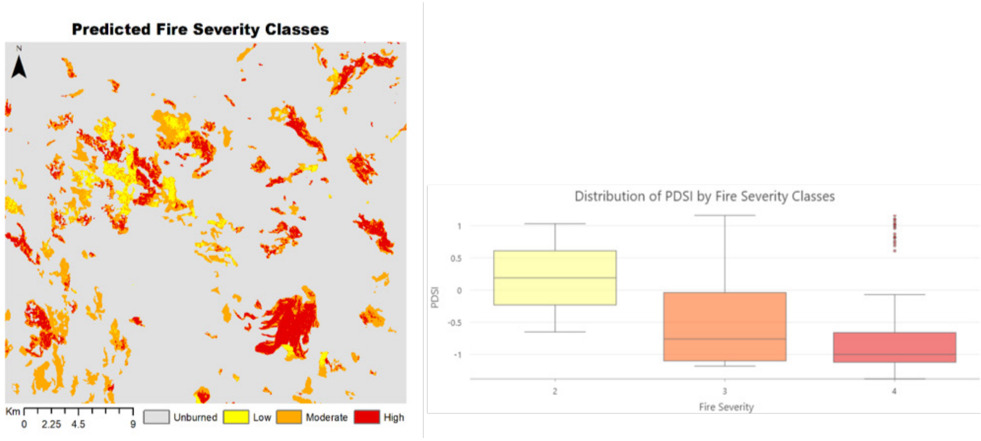
Our research was conducted in three sequential steps: mapping fire severity, identifying anomalies in climate hazards, and modeling the connections between fire severity (the target variable) and extreme climate hazards (the predictors). First, we utilized a Residual Attention UNet (RAUNet) for predicting fire severity classes. The RAUNet was trained on a substantial dataset comprising nearly 12,000 samples, which included image patches and their corresponding fire severity labels. The image patches were derived from a composite dataset incorporating dNBR2, dBAIS2, dMIRBI, dMNDWI, and pre- and post-fire of B11and B12 bands, derived from the Sentinel-2 satellite imagery. Subsequently, we accessed the TerraClimate dataset to extract a time series of monthly climate data and climatic water balance indicators, encompassing 14 variables, spanning from 1958 to 2023. Utilizing this data, we generated long-term monthly anomaly maps for various climate events, including droughts, heatwaves, evaporation and transpiration rates, and deficits in soil moisture. Lastly, we developed two GeoAI-based models to delineate the relationship between fire severity and extreme climate hazards. These models were trained using a forest-based approach and boosted algorithms on two-thirds of our dataset. The remaining one-third of the dataset served for model evaluation, employing metrics such as the F1-score, precision, and recall assessing performance.

Expected results

Our initial findings demonstrate that the RAUNet, tailored for our study, achieves high accuracy in mapping fire severity across low, moderate, and high categories within the miombo ecoregion, achieving F1 scores of 0.929, 0.784, and 0.924, respectively. As our analysis progresses, we intend to reveal key insights during the conference, specifically focusing on identifying the extreme climate variables that significantly influence fire severity in woodlands. We will highlight the relative importance of each climate predictor in determining fire severity and compare the efficacy of our GeoAI models (i.e., random forest and extreme gradient boosting) in predicting fire severity classes, taking into account these extreme climate hazard predictors. We will report optimal parameters and results of evaluation metrics for each model. Additionally, we plan to delve into the partial dependency interactions between forest fire severity and individual predictors. This analysis will elucidate the relationship between fire severity and each climate predictor, as well as explore the combined impact of multiple predictors on fire severity. Through this approach, we aim to identify critical thresholds within extreme climate conditions that correlate with increased fire severity.

Outlook for the future

The RAUNet model we developed shows strong performance in identifying both low and high fire severity classes. However, its ability to accurately map moderate fire severity requires enhancement through either dataset refinement or architectural modifications of the model itself. While our study utilized TerraClimate data at monthly intervals, future research should consider employing data with finer temporal resolution to potentially augment the model’s precision in predicting fire severity classes. Our investigation was confined to the Mozambican section of the miombo ecoregion. Extending this research to encompass the entire miombo ecoregion across southern Africa would provide a more comprehensive understanding of the model's applicability and the dynamics at play. Also, there is a vital need to examine the impact of a broader range of predictors on fire severity, such as human-induced, vegetation and the environment predictors. This will enhance our grasp of the multifaceted influences on fire severity, paving the way for more nuanced predictions and management strategies.



(A) example of predicted fire severity classes and (B) relations between fire severity and drought severity based on Palmer Drought Severity Index (PDSI).

Mapping Fire Severity Based on Sentinel 2 Earth engine Compositing Imagery for the Northern Region of México

Adrián Israel Silva-Cardoza[1,*], Daniel José Vega-Nieva[1], Jaime Briseño-Reyes[1], Carlos Briones Herrera[1], José Javier Corral Rivas[1], Pablito Marcelo López Serrano[1], José Luis Silván-Cárdenas[2], Eduardo Cruz Castañeda[3], César Alberto Robles Gutiérrez[3], Juan Miguel Campos Muñoz[3], Yair Ricárdez3, Fabiola Esquerra[3], Alicia Verónica Salas[3], Ursula Berenice García Herrera[3]

1 Universidad Juárez del Estado de Durango, México
2 Centro de Investigación en Ciencias de Información Geoespacial, México
3 Comisión Nacional Forestal, México

**Corresponding author:* adkrdoza @hotmail.com

Keywords: Sentinel-2; post-fire severity; image compositing; vegetation phenology

Challenge

The remote sensing of fire severity and burned area is fundamental in the evaluation of fire im-pacts. The current study aimed to: (i) compare Sentinel-2 (S2) spectral indices to predict field-observed fire severity in Northern Region of Mexico; (ii) evaluate the effect of the compositing period (1 or 3 months), techniques (average or minimum). The Relative Burn Ratio (RBR), using S2 bands 8a and 12, provided the best correspondence with field-based fire severity (FBS). One-month percentile 25 composites showed the highest correspondence with FBS (R2 = 0.87). These results suggest a promising potential of the phenological correction to be systematically applied with automated algorithms to improve the accuracy and robustness of fire severity and perimeter evaluations.

Methodology

Location. We selected 9 fires that occurred between 2019 and 2022, covering a gradient in fuel types and climates ranging. Field Sampling of Fire Severity. We measured a total of 389 circular plots (30 m in diameter), within the fire perimeter (290 plots), as well as unburned patches (90 control plots). The field protocol for fire severity was based on the methodology for temperate forest described by Silva-Cardoza et al. [2,3]. Both vegetation and soil strata were measured. Spectral Indices Analyzed. The spectral indices analyzed for fire severity discrimination are based on the Normalized Burn Ratio (NBR). We calculated the difference in spectral values between pre- and post-fire dates (dNBR), as well the Relativized Burn Ratio (RBR). In order to account for phenological and weather-related influences between the pre- and post-fire images, we considered the phenologically corrected spectral indices. Composite Periods and Techniques Analyzed. Sentinel-2 for each 1- and 3- month composites were generated and downloaded from Google Earth Engine (GEE). Predicting Fire Severity from Spectral Indices and Composites. We evaluated linear and non-linear regression models to predict composites-image spectral indices from field-measured severity variables. Model goodness of fit was evaluated based on the squared correlation coefficient between the predicted and observed values (R2) and their Root Mean Square Error (θ, RMSE).

Expected results

The current study analysed the precision of S2 spectral indices to map fire severity and burned area perimeter in Mexico. It included an evaluation of GEE, composite length, and technique and tested a phenological correction (c) method. One-month GEE composites, using the percentile 25 metric for composite images, showed a higher correspondence with field severity than 3-month composites or using the average. The offset "c" composites showed both improved correspondence with field fire severity for most sites and periods analyzed. This latter improvement was more significant in sites and periods where phenological effects (as quantified by changes in the dNBR in the unburned area) were stronger. Because strong and heterogeneous fuel phenology effects have been frequently observed, the "c" method could have the strong potential to significantly improve the accuracy of fire severity and burned areas if routinely applied in post-fire evaluations. The "c" approach, using the RBR to systematically stratify fuels and sample the spatially variable temporal variations in the spectral indices of the un-burned fuels, goes beyond the constant offset method in incorporating fuel heterogeneity but shares its relative simplicity of being fully automated. Including such a spatially variable phenological correction into existing automated tools, such as GEE, could contribute to deriving improved, systematic large-scale evaluations of fire severity and perimeters in Mexico and elsewhere.

Outlook for the future

In this sense, this method can capture phenological changes of varying magnitudes, potentially reflecting a variety of greening/drying conditions between different fuels, specific to each location and assessment time. The portability of the c method suggests the potential for improved analysis in a variety of locations and assessment periods, as it minimizes non-fire-induced changes in vegetation dynamics. This could improve the transferability of fire severity thresholds, again, because it minimizes fuel-specific variations in phenological and weather influences. Further research in spatial and temporal variations of phenological corrections across a large variety of ecosystems should be encouraged and ultimately incorporated into operation-al burned area and fire severity mapping efforts, potentially improving their accuracy and robustness.

The Importance of a Buffer Window in the Evaluation of GEO Satellite Fire Detection Algorithms

Asaf Vanunu[1],[*], Rodney Fonseca[2], Meirav Galun[2], Boaz Nadler[2], Arnon Karnieli[1]

1 University of Ben Gurion, The Remote Sensing Laboratory, Israel
2Weizmann Institute of Science, Israel

**Corresponding author:* asafyu@post.bgu.ac.il

Keywords: geostationary, evaluation, GOES, VIIRS, fire products

Challenge

Geostationary Earth Orbit (GEO) satellite imagery is utilized for fire detection. Indeed, most GEO systems provide fire detection products. Two key quantities that characterize measures for evaluating their fire products are omission and commission errors. A key question is how to assess the performance of a given fire detection algorithm. A prevalent approach is to use matching images of Low Earth Orbit (LEO) satellites as ground truth. However, using LEO data as ground truth is not straightforward. Notably, there are misalignments (geolocation shifts) between the locations of fires in GEO and LEO satellite images. This raises several fundamental questions: (1) what is the prevalence of these misalignments? and (2) how these potential misalignments should be taken into consideration in evaluating the accuracy of fire detection algorithms? The overarching goal of the current project is to explore the use and effect of a buffer window for registering the fire-detected pixels of the GEO satellite with those of the LEO ones.

Methodology

We developed an approach to address the impact of varying window sizes on the performance of the Geostationary Operational Environmental Satellite (GOES) fire product. The Visible Infrared Imaging Radiometer Suite (VIIRS) images were used as ground truth reference. GOES Fire and Characterization (FDC) images were filtered based on a temporal overlap of ±5 min from a VIIRS image. VIIRS data were projected into GOES grid. The output is a GOES grid where each pixel is assigned the number of VIIRS pixels that intersect with it. The analysis was performed in three settings. A ground truth fire-labeled pixel from the VIIRS output was considered as fire if there were (1) one or more VIIRS fire pixels; (2) five or more VIIRS fire pixels; and (3) ten or more VIIRS fire pixels. Four different sizes of buffer windows were tested for each setting: 1x1; 3x3; 5x5; and 7x7 (Fig. 1). A buffer window was employed to determine false alarms and omission errors based on the VIIRS output. The buffer window was applied for each GOES fire pixel. The pixel is considered a true positive if it contains a VIIRS fire pixel, indicating that both GOES and VIIRS detected the fire. Otherwise, it is a false positive (false alarm) pixel. Similarly, a buffer window was applied to each VIIRS fire pixel. If this window contains a GOES fire pixel, it is a true positive; otherwise, it is a false negative (omission error) pixel. Then, recall, precision, and F1 scores were computed.

Expected results

The main result from our analysis suggests that employing a buffer window produces higher precision, recall, and F1 scores than not using a window. This is true across all buffer window sizes and the number of VIIRS fire detections required to declare a fire. The 7x7 window yielded the highest precision, recall, and F1 scores. However, applying a 7x7 window may include neighboring fires not part of the initial fire cluster, potentially leading to inaccurate estimates. Therefore, opting for the 5x5 window size reduces the likelihood of accuracy errors of this kind. The results underscore the necessity and importance of incorporating a buffer window around GOES fire pixel detections. Failing to include such a window can lead to potentially misleading conclusions and significantly higher omission and commission errors.

In addition, we examined the probability of the FDC to detect a fire as a function of the number of VIIRS fire detections within a window around it. This analysis reveals a tradeoff between the likelihood of GOES fire detection and the amount of available data. Increasing the number of VIIRS fire pixels within a GOES pixel as ground truth increases the probability of GOES fire detection. However, this augmentation comes at the expense of a reduction in the quantity of these pixels. Our findings suggest that employing three to five VIIRS fire-labeled pixels as ground truth balances detection probability and data availability.

Outlook for the future

In forthcoming research, it is possible to enhance the methodology by adjusting window sizes based on geographic variables such as latitude and longitude. This approach would consider the varying characteristics of different regions and optimize the window size accordingly. For instance, areas closer to the equator may require smaller window sizes than regions at higher latitudes. The presented methodology can be implemented with minor adaptations to other GEO fire detection algorithms. Furthermore, our methodology can be extended to label GEO images using LEO data to train machine-learning algorithms. Until geolocation errors between GEO and LEO data are systematically corrected, the buffer window enhances the evaluation of fire detection algorithms. It offers a straightforward approach that does not necessitate any data corrections, thus making it relatively simple to implement.

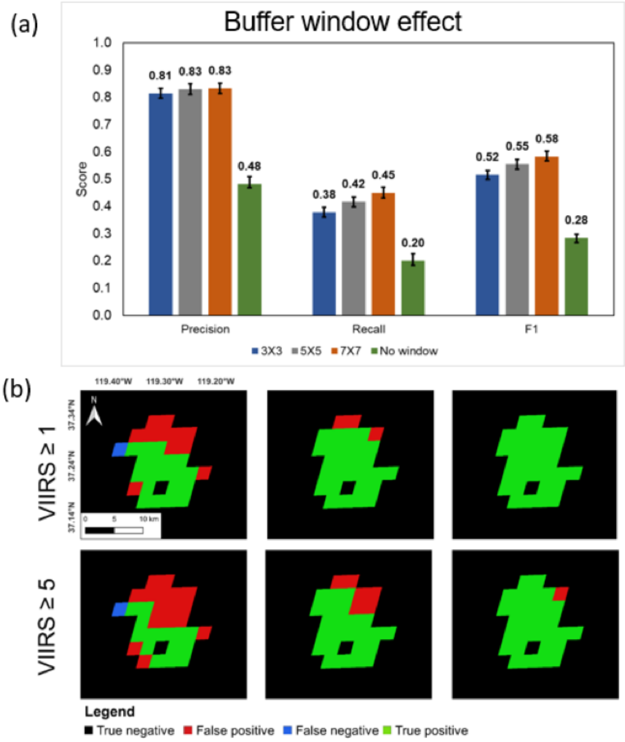


Figure 1. (a) example of a buffer window effect on accuracy measurements (b) example of a buffer window effect on GEO fire detection evaluation.

Examining Climate Drivers and Land Cover for Mediterranean Burned Area Prediction

Gabriele Vissio[1,2,*], Mara Baudena[1,2], Paolo Fiorucci[3], Antonello Provenzale[4,2], Marco Turco[5]

1 *CNR, Istituto di Scienze dell'Atmosfera e del Clima (ISAC), Torino, Italy*
2 *National Biodiversity Future Center, Palermo, Italy*
3 *CIMA Research Foundation, Savona, Italy*
4 *CNR, Istituto di Geoscienze e Georisorse (IGG), Pisa, Italy*
5 *Regional Atmospheric Modelling (MAR) Group, Department of Physics, Regional Campus of International Excellence Campus Mare Nostrum (CEIR), University of Murcia, Murcia, Spain*

* *Corresponding author:* gabriele.vissio@cnr.it

Keywords: burned area extension, climate drivers, land cover, random forest regression, Mediterranean fires

Challenge

The Mediterranean region is vulnerable to extended forest fires, with dramatic effects on human activities and ecosystems alike. Such events are usually driven by weather conditions prone to fire spread (e.g. windy and dry weather) and coincident with antecedent drought conditions. Land cover type and characteristics play also a key role in shaping fuel type and flammability and thus facilitating or hindering fires. It is therefore of the utmost importance to characterize those weather conditions favouring the onset of fires, along with land cover typologies more prone to host them, in order to describe the conditions leading to dramatic past events and, more importantly, to provide reliable predictions of the fire extent when in presence of a particular set of climatic conditions and land cover. Moreover, ranking the relative importance of such drivers in relation to their influence on forest fires may help to identify areas endangered by changing climatic conditions.

Methodology

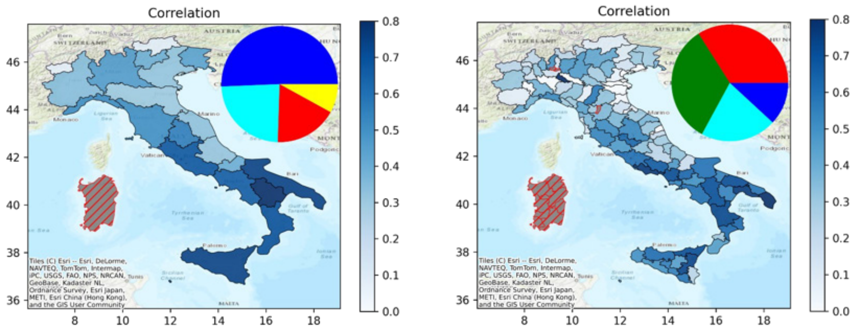
In order to predict the extent of the burned area, we perform a leave-one-out random forest regression using coincident climate conditions and land cover as predictors. Specifically, we aggregated burned area data at the monthly and regional scales for each driver and for the burned area, using the former together with land cover data from Corine to predict the latter. The leave-one-out procedure is performed making use of all the data related to all the regions, excluding one year from the training set, thus predicting such year in the testing phase and repeating the whole process for all the years of the dataset. Indeed, climate and land cover should be related not only to the current conditions of the area, but also to their latitudinal position - e.g., southern regions usually exhibit higher temperatures and solar radiation and lower precipitation -, thus justifying the use of the whole national cover as a training set. Furthermore, we aim to rank the drivers with respect to the prediction computing their permutation feature importance, examining if and how the quality of the prediction and importance of the drivers change when shifting from NUTS2 (regional) scale to NUTS3 (provincial) scale.

Expected results

Providing a ranking of the different drivers allows to shed light on the mechanism promoting or opposing fires in a Mediterranean scenario, in particular comparing the effect of climatology and ecology. As a test country for our approach, we employ the Italian territory, which spans through largely different climatological and ecological regions. Preliminary results show that land cover is important at the province scale, whilst much less at the regional scale where climatology is essential. Regarding climatological variables, several quantities are involved with wildfires, yet including all of them can soften the effect on our results due to the collinearity among them - i.e. the information carried by those variables is likely to be redundant. Thus, a suitable selection of variables must be undertaken in order to reduce them with an affordable loss in predictive skills. Moreover, whilst land cover gains relevance in modelling forest fires at small scales, it becomes interesting to find out how each cover type - suitably aggregated - influences the outcome of our model. As a matter of fact, such approach allows to emphasize the most important factors needed to provide a prediction, but their effect - as a promoter or as an opposer - still remains debated.

Outlook for the future

Land cover does not show the rapid fluctuations typical of meteoclimatic conditions, nevertheless its time scale variabilty is of the order of a decade, thus varying in a relevant manner in the investigated time range. Therefore, as a further development we will include several land cover maps, in order to take into account such temporal variability - at least partially. Furthermore, as different technologies often provide different outcomes, an intriguing perspective will be given by employing more datasets for the burned area, thus investigating those predictors which show the largest usage as predictors. Finally, applying this methodology to other fire-prone countries, e.g. Portugal or Spain, could highlight its applicability and, moreover, which predictors are useful to model the area burned by fires in the Mediterranean basin, pointing out the conditions leading to such events.



The maps show the correlation between burned area prediction and data at (left panel) Regional scale (NUTS2) and (right panel) Provincial scale (NUTS3). The pie charts show the permutation importance of the first four predictors in each case. The five predictors shown (and their color code) are: volumetric soil water content (blue), relative humidity (cyan), 2m temperature (red), solar radiation (yellow) and grasslands (green).

Classification of Fuel Types for Sardinia Region (Italy) from Time Series of Sentinel-2 Data in the Framework of the FirEUrisk Project

Debora Voltolina[1,*], Daniela Stroppiana[2], Forough Rajabi[3] Michele Salis[4], Bachisio Arca[4], Simone Sterlacchini[1], Mariano García[5], Emilio Chuvieco[5]

1 CNR, Istituto di Geologia Ambientale e Geoingegneria (IGAG), Milano, Italy
2 CNR, Istituto per il Rilevamento Elettromagnetico dell'Ambiente (IREA), Milano, Italy
3 Politecnico di Milano, Dipartimento di Ingegneria Civile e Ambientale (DICA), Milano, Italy
4 CNR, Istituto per la BioEconomia (IBE), Sassari, Italy
5 Universidad de Alcalá, Environmental Remote Sensing Research Group, Department of Geology, Geography and the Environment, Alcalá de Henares, Spain

* *Corresponding author:* stroppiana.d@irea.cnr.it

Keywords: supervised classification, fire risk, forest cover, vegetation indices

Challenge

Mapping fuel types and models is crucial for wildland fire risk prevention and management across multiple spatial and temporal scales due to the tight dependence of fire ignition, spread, and growth on vegetation characteristics. This work was developed within the activities of the FirEUrisk project (Developing a holistic, risk-wise strategy for European wildfire management) and lays its methodological foundations in the continental scale fuel type map for Europe at 1 km spatial resolution developed within the project. However, the extreme spatiotemporal variability of fuel characteristics, especially in Euro-Mediterranean biomes, with the consequently varying impacts on fire behaviour, requires further efforts to develop higher resolution fuel type maps. The objective of this work is to produce a high-resolution fuel type map over Sardinia, Italy, a pilot site of the FirEUrisk project, for the years 202-2021.

Methodology

The methodology for mapping fuel type at regional scale relies on the hierarchical-multipurpose fuel classification system proposed within the FirEUrisk project to map fuel type at the European scale. The proposed method delivers two thematic products: i) full resolution pixel based classification of fuel type categories (10 m) and ii) aggregated product of fractional cover to estimate density (100 m). The core pixel scale supervised classification is based on a Gradient Tree Boosting algorithm; training of the algorithm is carried out with a Python-based web application developed for the FirEUrisk project that allows the expert to label Regions Of Interests (ROIs) by photointerpretation based on orthophotos, Google Satellite and Street View maps as well as Sentinel-2 (S2) harmonized time series of spectral indices. The full resolution 10 m fuel type map is aggregated at 100m by 100m to estimate fractional cover (density of forest cover) that considers spatial heterogeneity of the vegetation cover.

Pre-processing of S2 time series consists of cloud and cloud shadow masking, generation of maximum value composites, generation of the spectral indices time series, fitting with complex harmonic models and generation of additional metrics (terrain and textural metrics). Among the input data we also considered: orthophoto mosaic of Sardinia region (2019, 0.2 m), Corine Land Cover map (2019, 10 m) for stratified random sampling of training ROIs, Digital terrain Model (DTM, 10 m) to derive elevation, slope and aspect, annual precipitation (2021, weather stations). We tested the following classification algorithms: Random Forest (RF), Gradient Tree Boosting (GTB), Support Vector Machine (SVM) and Convolutional Neural Network (CNN) over S2 tile T32TMK, western Sardinia, Italy.

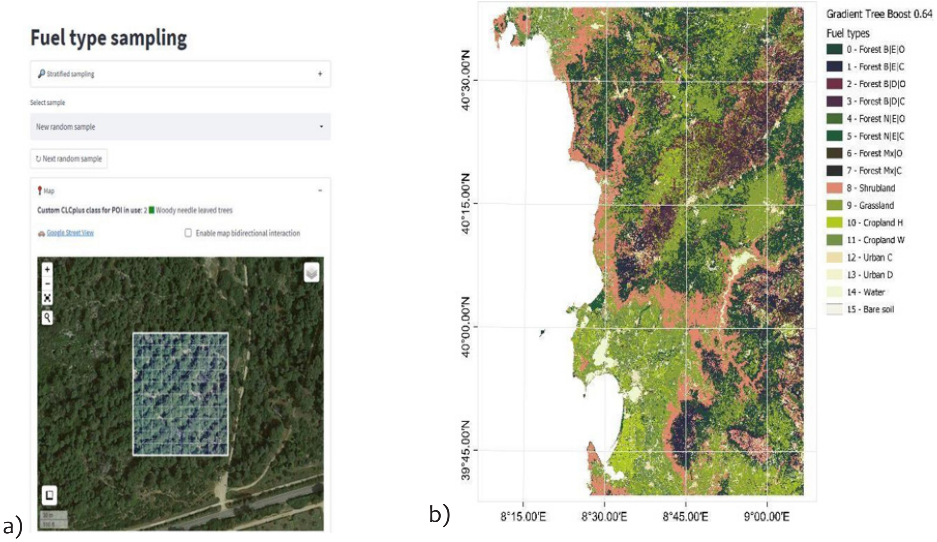
Expected results

The output fuel type map provided information at 10 m spatial resolution of the pixel vegetation cover among one of the following classes: broadleaved evergreen/deciduous forest, needleleaf evergreen/deciduous forest, mixed forest, shrubland, grassland, cropland. The aggregated product, at 100 m spatial resolution, add information on the density expressed as percent of cover (open: 15%-70%, closed: > 70%). The classification algorithm that provided the best results was Gradient Tree Boosting; the output fuel type map was evaluated by cross-validation testing on the training dataset delivering overall accuracy of around 90%. Accuracy was assessed by testing models with and without the contribution of annual precipitation, results showed that by taking into account this parameter among the set of input data, overall accuracy slightly increased (OA ~ 91%).

Outlook for the future

This work presents a methodology for mapping fuel type classes at 10 m resolution based on Sentinel-2 time series. The methodology was developed to generate a two-scale product to provide information on the vegetation type (10 m) and density (100 m).

The output pixel-based map derived over a single S2 tile in western Sardinia and with the GTB algorithm was tested with cross-validation providing around 90% overall accuracy. Further steps will foresee the extension of the classification to the entire Sardinia region by collecting additional training ROIs. Moreover, an independent validation will be carried out to assess accuracy of the product (both fuel class and density) over the entire region.



Fuel type sampling

Stratified sampling

Select sample: New random sample

Next random sample

Map

Custom CLCplus class for POI in use: 2 🟩 Woody needle leaved trees

Google Street View

☐ Enable map bidirectional interaction

Figure(a) The Phyton-based web application developed for the FirEUrisk project to collect training data (b) Example output product showing the fuel type classes for western Sardinia, Italy, covering S2 tile 32 TMK.

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