Guidelines for the institution of a national wildfire EWS and establishment of EWEA strategies

Prevention, Preparedness and Response to natural and man-made disasters in Eastern Partnership countries - phase 3 (PPRD East 3)

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Abbreviations

CBRNE	Chemical, Biological, Radiological, Nuclear and high yield Explosives
CP	Civil Protection
DEM	Digital Elevation Model
DLD	Disaster Loss Data
DRA	Disaster Risk Assessment
DRM	Disaster Risk Management
DRMKC	Disaster Risk Management Knowledge Centre
DRR	Disaster Risk Reduction
EFFIS	European Forest Fire Information System
EO	Earth Observation
EU	European Union
EC	European Commission
EU MS	European Union Member States
EUSF	European Union Solidarity Fund
EWEA	Early Warning to Early Action
EWS	Early Warning System
FDI	Fire Danger Index
FFMC	Fine Fuel Moisture Content
FWI	Fire Weather Index
GAR	UN Global Assessment Report on Disaster Risk Reduction
GNI	Gross National Income
GNP	Gross National Product
GDP	Gross Domestic Product
HVRA	Highly Valued Resources and Assets
IFRC	International Federation of Red Cross and Red Crescent Societies
ISIC	International Standard Industrial Classification of All Economic Activities
ISO	International Organization for Standardization
IRDR	Integrated Research on Disaster Risk
JRC	Joint Research Centre, European Commission's science and knowledge service
LEMA	Local Emergency management Agency
ML	Machine Learning
NDRA	National Disaster Risk Assessment
NWP	Numerical Weather Prediction

PPF	Probability of Propagation of Fire: factor that reduces danger estimates in not-fire-prone areas.
PPRD East 3	Prevention, Preparedness and Response to natural and man-made disasters in Eastern Partnership countries Phase 3
RoS	Rate of Spread
SAR	Support Search and Rescue
UAV	Unmanned aerial vehicles
UNISDR	United Nations International Strategy for Disaster Reduction (from 2019 UNDRR)
UNDRR	United Nations Office for Disaster Risk Reduction (formerly UNISDR)
USD	United States dollar
WP	Work Package

1. Purpose and Objectives

1.1. Main objectives

Wildfires can have devastating effects on communities and ecosystems, causing loss of life, property damage, and environmental degradation. Therefore, it is crucial to have an effective Early Warning System (EWS) in place to alert the Civil Protection (CP) system and the population in a timely manner. This ensures the enactment of necessary anticipatory actions and precautions, to minimise behaviours that could lead to wildfires as well as to support timely detection and fast response to eventual ignitions.

Acknowledged as a major element of disaster risk reduction, the importance of multi-hazard EWSs is highlighted also in the Sendai Framework for Disaster Risk Reduction 2015–2030, which sets a global target (target G) to enhance their availability and accessibility by 2030. The PPRD East 3 programme has been tailored to assist programme Countries in improving national performance across various indicators, particularly target G.

Indeed, under the framework of the programme, a set of tools and processes has been introduced to facilitate the establishment and implementation of a national wildfire EWS. So, the following guidelines aim to provide a comprehensive support for crafting effective alerting procedures and fostering Early Warning to Early Action (EWEA) strategies, on the base of the work done during the PPRD East 3 activities.

The guidelines follow the UNDRR definition, which consider an EWS as an integrated system comprising different components, including disaster risk knowledge, monitoring and warning services, communication and dissemination, and emergency response capacity. While providing a general framework to the development of an EWS and EWEA strategies as related to wildfires, the document addresses specific issues, including the identification of key stakeholders, the selection of appropriate technologies and tools for pre-emptive monitoring and rapid detection, the establishment of communication channels for the timely dissemination of information and warnings to relevant parties, and the development of trigger/threshold mechanisms for early actions. Some chapters will directly refer to other PPRD East 3 guidelines covering specific elements.

Hence, the broader purpose of the guidelines is to secure the sustainability of the extensive process initiated by the programme in assisting the development of a system capable of providing valuable information to competent stakeholders, who can, in return, pre-activate authorities and communities about potential wildfire risks using predefined thresholds and analytical criteria.

1.2. Terminology

In the guidelines a specific terminology will be used. The following are the most recurrent terms and their explanation. The primary reference for terminology will be UNDRR [1].

[1] https://www.undrr.org/terminology

Contingency planning: A management process that analyses disaster risks and establishes arrangements in advance to enable timely, effective and appropriate responses.

Early warning system: An integrated system of hazard monitoring, forecasting and prediction, disaster risk assessment, communication and preparedness activities systems and processes that enables individuals, communities, governments, businesses and others to take timely action to reduce disaster risks in advance of hazardous events.

Effective "end-to-end" and "people-centred" early warning systems may include four interrelated key elements: (1) disaster risk knowledge based on the systematic collection of data and disaster risk assessments; (2) detection, monitoring, analysis and forecasting of the hazards and possible consequences; (3) dissemination and actionable warnings and associated information on likelihood and impact; and (4) preparedness at all levels to respond to the warnings received. These four interrelated components need to be coordinated within and across sectors and multiple levels for the system to work effectively and to include a feedback mechanism for continuous improvement. Failure in one component or a lack of coordination across them could lead to the failure of the whole system.

Early Warning to Early Action: Early action, also known as anticipatory action or forecast-based action, means taking steps to protect people before a disaster strike based on early warning or forecasts. To be effective, it must involve meaningful engagement with at-risk communities.

Multi-hazard early warning systems: address several hazards and/or impacts of similar or different type in contexts where hazardous events may occur alone, simultaneously, cascadingly or cumulatively over time, and considering the potential interrelated effects. A multi-hazard early warning system with the ability to warn of one or more hazards increases the efficiency and consistency of warnings through coordinated and compatible mechanisms and capacities, involving multiple disciplines for updated and accurate hazards identification and monitoring for multiple hazards.

Hazard: A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption, or environmental degradation.

1.3. Wildfires tools at a glance: PPRD East 3 framework for wildfire EWS

The PPRD East 3 programme has developed various tools designed to support the development of a national EWS and EWEA strategies as related to wildfires, contributing, overall, to different phases of wildfire management. Moreover, each programme Country has been granted exclusive access to the "myDEWETRA.world", which is an open-source web-based system for real-time monitoring and forecasting of natural hazards. The platform has been meticulously customized and furnished with data and models specific to each individual country. It includes the tools developed by the programme, such as maps, models, wildfire propagation models, earth observation products such as wildfire hotspots, and integrates an application for producing and disseminating wildfire danger bulletins.

This introduction briefly outlines where these tools can be applied within the wildfire management and EWEA cycle, and where they are detailed in the present guidelines.

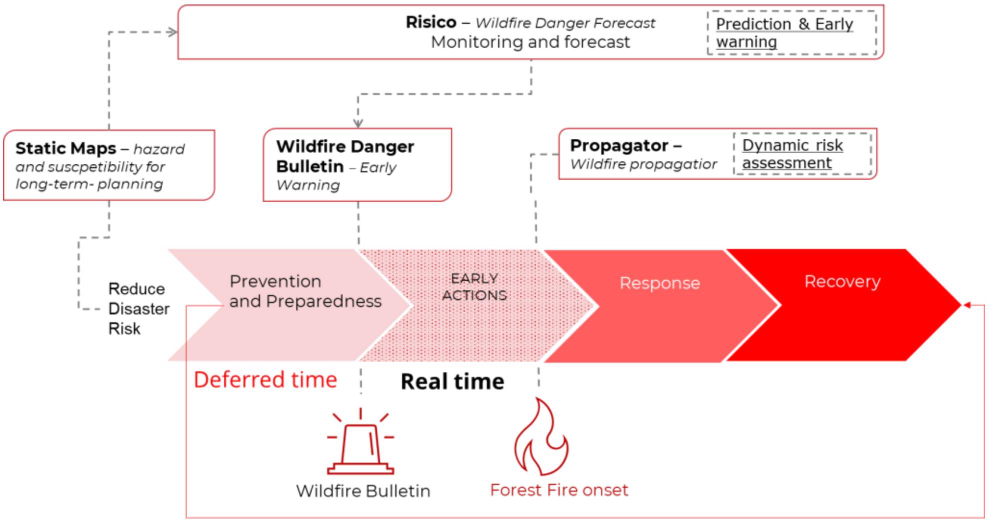


Figure 1: Use of the wildfire tools provided by PPRD East 3 within the wildfire management cycle.

Wildfire management encompasses three main phases: Prevention & Preparedness (including Early Warning issuance and Early Actions), Response, and Recovery. Each phase benefits from specific tools that facilitate key activities.

For instance, during the Prevention & Preparedness phase, static maps provide crucial insights into hazards and vulnerabilities essential for long-term planning. These maps also prove valuable during the Recovery phase, aiding efforts in restoring affected areas and planning for future resilience, as detailed in Chapter 3 on disaster risk knowledge.

In Prevention & Preparedness, the RISICO model developed by the programme plays a pivotal role by forecasting wildfire dangers, enabling effective monitoring and early warnings. Additionally, the Wildfire Danger Bulletin enhances early warning capabilities, ensuring timely and well-informed preventive measures. Both tools are detailed in Chapter 4, focusing on EWS for wildfires.

During the Response phase, when fire events occur, the PROPAGATOR tool becomes essential for dynamic risk assessment and supporting firefighting operations. It also can be used to develop risk scenarios and planning fuel management strategies. Further details on PROPAGATOR are provided in Chapter 3 on disaster risk knowledge.

Overall, these tools are integrated into the wildfire management cycle to enhance preparedness, response efficiency, and long-term recovery efforts, adapting to varying wildfire scenarios and contributing to national resilience strategies.

Purpose	Time scale	Name of product
Prevention and preparedness; Resource allocation; EWS;	Three-hourly data up to 4-5 days before the event;	RISICO Chapter 4
Scenario analysis; Planning via scenario making; Assistance to firefighting corps	Simulation of a fire event up to 24-48 hours of fire evolution, with 10 minutes resolution. Few minutes to complete task	PROPAGATOR Chapter 3
Long term planning and restoration phase; Static factor to tune RISICO EWS	Static map (one per wildfire season, depending on wildfire regime)	STATIC MAPS Chapter 3
Development and issuance of a bulletin	Daily, with 3 days forecast	BULLETIN application Chapter 4

Table 1: Map of the Wildfire EWS tools, with their purpose and time scale.

2. Organizational Structure

2.1. Main actors involved in the wildfire risk management – EWS for wildfires

A well-defined governance and institutional structure are essential for the establishment and sustainability of an effective EWS. Clearly outlined roles and responsibilities for all stakeholders are crucial for task assignment, facilitating decision-making processes, and understanding lines of authority. This includes for example, clarifying who is responsible to issue EWs, disseminate alerts, and activate the system.

Early warning mechanisms can correspond to very different institutional arrangements, operational procedures, technical and scientific activities and communication mechanisms depending on each country's specificities, such as level of decentralization, authorities, legislation and resources.

In this framework, these guidelines include only a general overview of the key actors typically involved in early warning activities for wildfires and their respective roles and responsibilities, providing necessary context for subsequent chapters.

While specific institutional arrangements may vary based on the legislative framework of each country, it is important to highlight that institutional partnership among different actors is always fundamental. This includes collaboration among stakeholders from different sectors, such as technical agencies and emergency authorities, as well as across different territorial levels, including national, local, and regional entities. Furthermore, in this context, the active participation of non-state actors is imperative to the design and dissemination of effective warnings and in ensuring that life-saving preparedness measures are actioned when alerts are issued.

Further details on the general roles of stakeholders in disaster risk management and planning can be found in the "*Emergency Planning guidelines*" developed within the framework of PPRD East 3.

2.1.1. Local Emergency Management Agency

The Local Emergency Management Agency (LEMA), in accordance with the legal framework, usually coordinates response activities and oversees information flows needed to have a constantly updated situation. It also establishes prevention and preparedness and Disaster Risk Reduction (DRR) strategies.

The LEMA has a significant role in defining the overarching framework and operative structure of the national Civil Protection system. Of special importance, for what concerns the present guidelines, is its pivotal position in the EWS. On the one hand it has the duty of designing the command-and-control chain and the communication flow between the involved stakeholders, on the other it also needs to provide guidance for the actuation of a functional warning system capable of reaching the most peripheral structures of the system. Usually, LEMA has also the responsibility of issuing EWs based on the forecasts and bulletins provided by the Hydrometeorological Centres.

To ensure sustainability and efficiency of the system the LEMA needs to constantly validate the EWS, establish dialogues with the end users and ensure that the provided information is applicable.

To assure rapid responses, modern EWS tend to allocate duties and their relative responsibility in accordance with the intensity and territorial extent of an event. While the Local Emergency Management Agency (LEMA) maintains the overall coordination and country-wise situational awareness, the various competences are often distributed from local to national level depending on the national framework and the capacity to cope with an extreme event.

This variable configuration allows an adequate and commensurate activation of the system while granting a distribution the overall coping capacity across the territory.

From local to national:

- For localized events, the responsibility is usually identified at the local level. In most cases, responsibilities for the emergency management are in charge of the Major or to the Municipality administrative level of the LEMA. The proximity between an event and response structures allows for a faster reaction and for the establishment of an advanced command post that immediately initiates monitoring activities.
- For complex events which by their nature and extent require coordination of resources at supra-municipal level, and when the coping capacity of the region/district/municipality is overwhelmed, the national level intervenes relocating on the area of the event its means and tools. The Local Emergency Management Agency itself takes coordination of the response.

2.1.2. Hydrometeorological Centre

Hydrometeorological Centres play a fundamental role in the EWS as within its experts resides the needed competence for the provision of hazard knowledge and situational awareness thanks to forecasts, monitoring networks and development of risk scenarios. These centres provide quality information and support the adoption of a scientific approach to civil protection activities.

A collaboration between the Hydrometeorological Centre and LEMA authorities is essential, despite their differing expertise and communication methods. Aligning communication ensures early warning messages can be translated effectively into early actions, enhancing the response capacity of civil protection actors. This partnership usually involves specified responsibilities, where the Hydrometeorological Centre takes the lead in forecasting hazards, while LEMA/civil protection authorities evaluate forecasts' implication using their practical field knowledge.

2.1.3. Technical services, forestry agency and line ministries and agencies

In the PPRD East 3 member states, ministries of environment and forestry agency play an important role in the wildfire national EWS.

Most of the time, they are in charge of forest maintenance and reforestation and endeavour the adoption of sustainable use of forested areas safeguarding their ecosystems.

2.1.4. Municipalities and local sections of LEMA

Municipalities and local expressions of the LEMA are the terminal of the EWS. They receive information from the National level and usually have the duty and possibility to activate EWEA protocols. This activation should be associated with threshold/trigger mechanisms that allows to combine forecasted danger indexes and on-site monitoring to operational phases within local plans. The local level of a civil protection system is usually defined as “last mile”. It has a role of significant importance in EWS. On the one hand it receives information coming from the national level, thus the system needs to be designed to provide adequate and informative materials. On the other hand, it is also where Anticipatory Actions are most effective if well planned.

Alerting protocols have the function of activating preventive mechanisms in different plans. Those, however, need to be developed based on possible risk scenario which consider the physics of the event, coping capacity, vulnerabilities, and exposed elements. To this end, a set of guidelines has been prepared within the PPRD East 3 programme to support the elaboration of full risk scenarios (*National Disaster Risk Assessment Guidelines*).

At local level it is of the utmost importance that different stakeholders cooperate and that interagency coordination is defined within a sound regulatory framework leaving no interpretation on roles and responsibilities of different actors as well as well-defined information flow.

Lastly, an effective EWS needs to factor into its implementing strategy also the population. Authoritative channels which disseminate civil protection information need to be acknowledged by the population and reachable with ease.

2.1.5. Civil Society Organizations

A structured set of Civil Society Organizations can support the Civil Protection system in various ways:

1) Support the drafting process of an emergency plan by providing territorial information and assessing the local coping capacity
2) Exert Anticipatory Actions stemming from a EW and its application within a local emergency plan. Such as:
    a. Active monitoring of identified hot spots
    b. Mapping of affected areas
    c. Support the closure or evacuation of potentially affected facilities
    d. Block roads

3) Conduct awareness raising campaigns to spread the knowledge of Civil Protection and facilitate the comprehension of the overall EWS within the population

2.1.6. Population

The population is usually considered as the "last mile" of an EWS. Institutional communications are useful if they are received and comprehended by the civil protection. Including participatory approaches in the establishment and design of an EWS can thus greatly increase the quality of the flow of information allowing at the same time the introduction of behavioural changes within the population.

2.1.7. Fire fighters and responders in general

Fire fighters are among the first responders to control and extinguish fires. Therefore, a timely and smoothly exchange of early warnings from the LEMA to responders can ensure that they are prepared to act when needed. This also applies to other available units expected to manage fires at the national and local level. However, it is important that responders and LEMA have a common understanding of what is expected from the responders based on predefined warning levels. The main focus of an EWS and, thus, of the present guidelines is to move the attention from the response to the prevention and preparedness phase which has to involve the main forces on the ground. This implies that responders should also be involved in prevention activities in order to lower the risk level.

3. Disaster Risk Knowledge: Hazard and risk scenarios

Understanding wildfire risks involves considering how hazards, people, assets, and their vulnerabilities interact in specific locations. This approach is thoroughly explained in the "*National Disaster Risk Assessment Guidelines*" provided by the PPRD East 3, which emphasize the different steps through a multi-hazard approach.

Instead, this chapter focuses on information tailored specifically for wildfires, highlighting which data and maps are crucial for identifying areas needing monitoring, establishing effective early warning, and planning responses. It covers essential aspects such as static information for disaster risk knowledge developed under the PPRD East 3 programme, methodologies for assessing wildfire hazards, and an in-depth look at PROPAGATOR for simulating fire propagation dynamics.

3.1. Development of static information for the definition of Wildfire hazard

Early Warning Systems rely on a set of information that allows decision makers and disaster risk managers to make the best use of the available resources in a given territory. Prior to the development of dynamic forecasting models (see chapter 4.1) the different hazards need to be mapped to identify areas which are prone to a specific hazard.

This procedure needs to be done using state of the art procedures and for all the most relevant hazards.

Static maps allow for a deeper knowledge of the territory, at national and regional level. Such maps are usually available in GIS format (such as raster format) and can be used as a standalone product, or as an input to dynamic (e.g., weather- dependent) danger models. Those maps can be used in the native resolution (with pixel-by-pixel information, depending on the resolution of the study) or can be aggregated at the desired level to summarise information accordingly.

In the case of wildfires, the PPRD East 3 programme has produced maps of the wildfire susceptibility and the potential fire line intensity. The latter maps have then been combined to produce national wildfire hazard maps. In the following, the three terms (susceptibility, fire line intensity and wildfire hazard) will be discussed, giving ultimately a broad definition of wildfire risk.

Susceptibility

Wildfire susceptibility is defined as the static probability of experiencing wildfires in a certain area, depending on the intrinsic characteristics of the terrain (Tonini *et al.* 2020). This can be achieved by adopting several approaches, ranging from statistical hierarchical ones to ML-based algorithms. Static susceptibility mapping involves the identification of areas that are at higher likelihood of wildfire ignition and spread based on various factors such as climate, vegetation, topography, and human activities. It is a layer with continuous values from 0 to 1, where 1 stands for high wildfire likelihood, and 0 stands for not fire prone areas.

Fireline intensity

Wildfire intensity is defined as the rate of heat energy released by the fire. It is linked to the flame length and more in general to the fire behaviour during a specific wildfire event. It can be reached through expert-based classification of fuel cover or by empirical models.

Wildfire Hazard

Wildfire hazard is indicated by the spatial distribution of the areas where a severe wildfire is likely to occur. This can be done by merging the outputs of the two previous steps by the means of empirical functions or via contingency matrices.

The importance of assessing the wildfire hazard, thus having available a hazard map at regional level, helps in the decision-making processes regarding medium-long term activities such as the planning of resource allocation.

Wildfire Risk

The most general framework for wildfire management involves not only Hazard assessment, but also Risk evaluations, which are generally harder to obtain and not trivial under many aspects. Risk maps for wildfires generally involve not only the maps for hazards and eventually ancillary data such as wildfire frequency / susceptibility, but they also incorporate in the analysis the Highly Valued Resources and Assets (HVRA) and their vulnerabilities to the wildfire that could potentially impact them. The main general formula for the risk evaluation reads (for further details look at Paragraph 3.3):

$R = f(H, V, E, C)$

Where H is the hazard, E the exposed elements (such as HVRA), V their vulnerability and C the response capacity of the system.

In the framework of the PPRD East programme, the analysis did not focus on the realization of national risk maps. Instead, hazard maps were produced at 500m of resolutions for all the programme Countries, while some examples of risk scenarios were developed for pilot cases. The latter examples were thought as scenario-based risk assessments, based on fire propagation scenarios provided by PROPAGATOR tool.

3.2. Hazard assessment methodology - Technical description

This chapter describes the methodology used to assess wildfire hazard within the framework of PPRD East 3 programme, providing a technical description of the different steps, including algorithms, input data used for the evaluation, parameters and classification of the outputs.

Hazard has been computed as a combination of two variables:

- Wildfire susceptibility
- Wildfire potential intensity

3.2.1. Wildfire Susceptibility

The adopted methodology for assessing the wildfire susceptibility relies on machine learning techniques. Machine learning can learn from available data. It has the ability of finding, through statistical analysis, hidden relations between features (that, in this case, are the climatic, terrain and anthropic features which constitute the set of wildfires predisposing factors) and a label (in our case, presence or absence of wildfires in a certain area), in order to predict wildfire likelihood. In the analysis carried out for the PPRD East 3 programme, the area of study has been discretized in a grid of pixels, with a resolution equal to the spatial resolution of the analysis (500 meters). The dataset, built for the machine learning procedures, includes all the pixels of the study area. Then, to each pixel the information of the predisposing factor and the binary label to predict is assigned. For extracting the label, the past wildfire burned area has been retrieved through EFFIS dataset or other services of EO-based burned area retrieval such as Firedpy (Mahood et al., 2022), and then rasterized to have a footprint of the burned regions. Thus, the pixels falling within areas that historically experienced wildfires assume label 1 (burned areas), while those that were not affected by wildfire according to the past fire database are 0-labelled pixels (unburned areas).

The algorithm selected for the analysis is the random Forest Classifier, which addresses the task as a classification problem, thus trying to classify into binary labels the points on the dataset. To do so, the dataset has been split in 2 subsets. The first one is used for training the model and it is a balanced subsample of the complete dataset of the study area, while the other is a test set, not used during the model training process. At the end, the results of the classification performed by the ML model on the test set are compared with the true label which the test set holds. The random forest classifier, being an ensemble algorithm, is able to give a value ranging from 0 to 1 for each pixel of the study area.

The goal is to find the relations between the past burned areas and the geo-topographic and climatic characteristic of the area, thus finding rules that can be applied to the whole territory, giving a value of the most fire prone areas, that are the areas in which a wildfire occurrence is more expected.

To do so, a list of predisposing factors is defined and has been associated with all the dataset pixels. For these analyses, only open data has been used. The analyses can be further improved considering national and local data of each programme Country if needed. See Table 2 for the list of the predisposing factors adopted in the presented analysis.

Predisposing factor	**Data source**
Elevation (DEM)	MERIT DEM (Yamazaki et al. 2017)
Slope	Processing from MERIT DEM
Exposition (northing and easting)	Processing from MERIT DEM
Land cover	Copernicus Global Land cover
Annual mean temperature	World Bank Climate Change Knowledge Portal
Annual mean cumulative precipitation	World Bank Climate Change Knowledge Portal
Koppen bioclimatic regions	gloH2O
Distance from primary and secondary roads	Processing from OpenStreetMap

Distance from cultivated lands	Processing from Copernicus Global Land cover
Distance from settlements	Processing from Copernicus Global Land cover

Table 2: List of the predisposing factors used in the analysis considers topographic and vegetation cover variables, climatic and urban-related variables

After a wildfire susceptibility ML model is trained, performance metrics can be extracted. This is a rather general step, that is to be undertaken for any adopted modelling choice, not only for ML approaches.

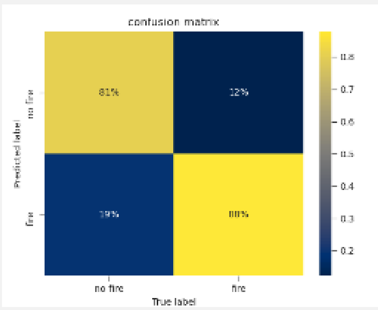
When building classification models for creating raster maps of natural hazard susceptibility, the testing phase is mandatory to evaluate the model's performance and ensure it doesn't overfit. Overfitting occurs when a classification model learns the details and noise in the training data to an extent that it negatively impacts the model's performance on new, unseen data. The test set helps us assess the model's generalization capability. Standard metrics used for this evaluation include Area Under the ROC Curve (AUC), accuracy, and Mean Squared Error (MSE) (Müller and Guido, 2018; Trucchia et al. 2022a). The AUC measures the model's ability to distinguish between classes, with higher values indicating better performance. A value higher than 0.8 is generally considered a good value in order to consider the model general enough. Accuracy calculates the proportion of correctly classified instances. MSE is used because the output raster ranges smoothly from 0 to 1, while the target raster (the wildfire test set) uses 0 and 1 to represent real past wildfires or areas where no wildfire took place. MSE quantifies the difference between these predicted and actual values, providing insight into the model's prediction errors. Lower values for MSE correspond to a better model (when no overfitting takes place).

Furthermore, post processing can be made to the model to assess the relative input factor relevance in assessing the fire prone areas. This is in line with the XAI, *eXplainable Artificial Intelligence* approach (Guidotti *et al.* 2018), that tries to limit as much as possible the presence of "black boxes" in the modelling paradigm, especially when ML is involved.

A) Performance on the test set

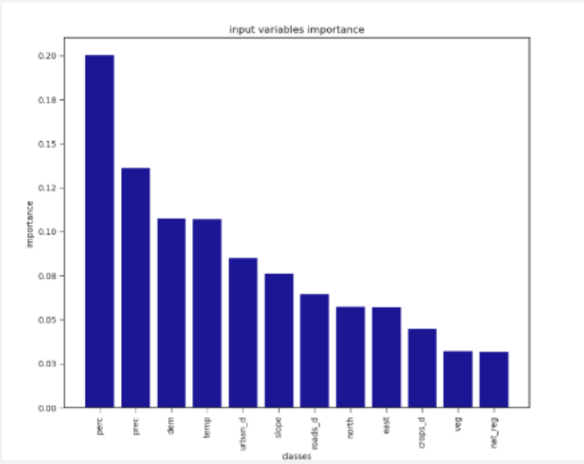
The performance of the model has been assessed by evaluating different scores based on the comparison between the model prediction and the true label for each pixel of the test dataset. The reported values are the ones of the Caucasus region analysis.

- Area under the receiving operator curve (AUC): 0.905
- Mean squared error (MSE): 0.121
- Overall accuracy (ACC): 0.84
- Confusion matrix (which shows us how many false positives and false negatives are present in the model evaluations)



Overall, the model performed well, both in the Caucasus and in Ukraine- Moldova test cases. The different analyses that were carried out show satisfactory scores, in line with literature (Trucchia et al. 2022b). See *Block A* for the performances of the susceptibility model on the test set. In *Block B*, the histogram of variable importance in determining the outcome of the model choices is given out. In *Block C*, the ability of the susceptibility map to assign high values to fire prone areas is tested with fires that never entered the model training phase.

B) Importance of the model feature in the classification

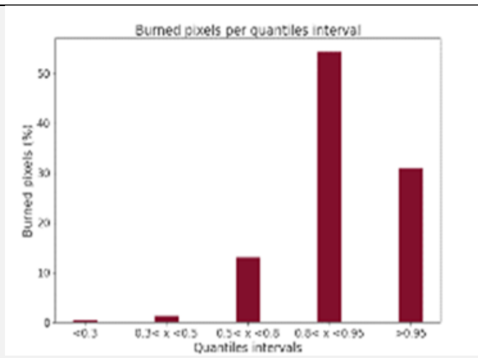


Most ML models allow insights on the different importance of the several inputs in determining the model's predictions. In the case of Random Forest algorithm, the input relevance can be produced by the so-called Gini impurity method (Breiman, 2001). The plot identifies which predisposing factor has gained more weight in deciding the model outcome, whether it is 1 or 0 labelled. The four most influential variable where the spatial arrangement and type of vegetation, the annual precipitations, the elevation and the average yearly temperatures.

C) Distribution of susceptibility values in test burned areas

The pixels corresponding to test fires are projected into the susceptibility map, which has values from 0 to 1, and divided into a set of quantile intervals (e.g., the top 0.95 quantile may have pixel with susceptibility higher than, let's say, 0.81, and so on). If the classifier model was successful, most of the test pixels falls in the top quantile intervals, meaning that also fire pixels which did not enter the analysis are classified in susceptible areas.

The plot underlines that the model, when it is asked to assign a susceptibility value to a pixel that de facto burned in the past, tends to assign very high susceptibility values, choosing susceptibility values that for the majority fall in the 20% of the highest values. In this last plot, the chosen wildfires were taken from a completely separate test dataset, so that the ML could not be overfit on that knowledge to guarantee good results.



The trained model has been run over the complete Caucasus region, Moldova and Ukraine obtaining the susceptibility maps which have been provided to each Country. The susceptibility has been aggregated into discrete classes following a percentile-based strategy.

Such classes are defined in the following table:

Classes	Description
1	Very low susceptibility
2	Low susceptibility
3	Medium susceptibility
4	High susceptibility
5	Very high susceptibility

Table 3: Classes of susceptibility used for the complete Caucasus region, Moldova and Ukraine

3.2.2. Potential Intensity layer

The next step has been the evaluation of the potential intensity. Its assessment has been based on a physical equation derived from the well-known Rothermel equation (Andrews 2018) for the rate of spread. The potential intensity, in fact, is defined as the multiplication of two terms, the rate of spread (RoS) and the vegetation load term (M):

$$I = RoS * M$$

Where:

- I is the potential fireline Intensity (kW/ m);
- RoS is the potential rate of spread (m/h) and it is defined as follows: $RoS = v_0 * \alpha_s * \alpha_w * \alpha_m$
- v_0 stands for the nominal rate of spread (m/h) available for every class of aggregated vegetation and presented in the following table.
- α_s stands for the correction due to the slope of the considered pixel. It is a factor ranging from 1 to 3 and has been computed pixel by pixel using the Digital Elevation Model (DEM).

- α_w stands for the correction due to the wind (considering wind magnitude and eventual up-hill or down-hill wind effects). It is a value ranging from 1 to 3. In order to do a worst-case scenario, a uniform value of 2.0 (that is quite high considering its uniformity over the entire territory) has been adopted.

- α_m stands for the correction due to the different fine fuel moisture content (FFMC) conditions. As before, in view of a worst-case scenario analysis, a uniform FFMC value of 0.05 has been selected, representing exceptionally dry conditions.

As mentioned before, M is the load mass term, that depends on slope and fuel type.
$M = LHV_{dead\ fuel} * Fuel_{load\ ground} + LHV_{canopy} * Fuel_{load\ canopy}$

- $LHV_{dead\ fuel}$ is the Low Heating Value obtained from the High Heating Value specific for each aggregated fuel type, after a FFMC correction (with FFMC chosen as 0.05).

- $Fuel_{load\ ground}$ is the fuel load at ground (kg/m^2), specific for each aggregated class.

- LHV_{canopy} is the Low Heating Value obtained from the higher heating values (HHV) specific for each aggregated fuel type, after the correction with the (vegetation type dependent) canopy humidity.

- $Fuel_{load\ canopy}$ is the fuel load at canopy level (kg/m^2), specific for each aggregated class.

#ID	Description	Fuel Load at Ground (kg/m^2)	Fuel Load at Canopy (kg/m^2)	Nominal Rate of Spread (m/h)	High Heating Value [kJ/kg]
10	Water bodies	-	-	-	-
11	Sparsely Vegetated Areas / Barren Areas	0.1	-	20	17000
21	Agricultural areas and Grasslands	0.5	-	120	17000
23	Agroforests	0.5	2	120	19000
32	Conifers	1	4	120	21000
34	Broadleaves	1.5	3	100	20000
37	Shrubs	1	3	140	21000

Table 4: Intensity parameters for fuel classes

Wind and moisture have been set to spatially uniform values.

3.2.3. Hazard computation

The hazard is given by the following adopted formulation:

$$H = I(0.5 + 0.5 * S)$$

Where I is the potential intensity and S is the susceptibility. Since S ranges from 0 to 1, I can be halved when computing the Hazard, or, in case of highest Susceptibility (that is, in the pixels where S = 1), the computed H coincides with I.

The computed maps of potential intensity and of wildfire hazard are available on myDEWETRA.world platform, both in native format and after class aggregation.

3.3. Risk scenario

In the field of natural hazards, the concept of disaster risk refers to "the potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity" [UNISDR, 2009].

Risk = Hazard x Exposure x Vulnerability / Capacity.

indicating that while hazard, exposure, and vulnerability increase risk, capacity mitigates it.

Commonly the risk is defined also as hazard x vulnerability, where the concept of vulnerability also underlies those of exposure and capacity. In fact, capacity can be imagined as a sort of downside of vulnerability. Nevertheless, the relationships between capacity and vulnerability are not trivial and the two concepts are not exactly interchangeable [Gallopín, 2006].

Risk assessment involves the following steps:

- hazard assessment.
- identification and characterization of exposed elements.
- vulnerability and capacity assessment.
- combination of previous steps and determination of the risk.

This procedure is not standardized all over the world and different methods to determine each of these steps exist in literature and have been implemented in tools and platforms for risk management.

For the definition and quantification of wildfire hazard please look at paragraph 3.2.

The PPRD East 3 programme has not developed wildfire risk maps at a regional or national scale but has instead created specific wildfire risk scenarios using the PROPAGATOR tool at pilot site.

Risk scenarios are a plausible description of how the future may develop. Scenarios should be based on a coherent and internally consistent set of assumptions about key relationships and driving forces. Usually, only a limited number of scenarios should be selected, e.g. by referring to some standard, such as a "reasonable worst case". At the stage of risk identification, scenario building must be devised in the most inclusive way and may refer to rough estimates or qualitative analysis.

The PPRD East 3 programme has a detailed "*National Disaster Risk Assessment guidelines*" and a specific annex for the elaboration of full risk scenarios. These provide a great support for the elaboration of detailed risk scenarios.

Moreover, for a comprehensive understanding of wildfire risk assessment methodology, including the evaluation of vulnerability, exposure, and coping capacity, the "*Technical Guidelines for Forest Fire Risk Assessment*" produced in the context of IPA FF programme serve as an essential reference.

3.3.1. PROPAGATOR

PROPAGATOR (Trucchia *et al.* 2020; Perello *et al.* 2024; López-De-Castro *et al.* 2024) is a cellular automata model for simulating the evolution of a wildfire event. It can easily simulate 24 hours of wildfire development in a matter of minutes. The model has a graphical user interface in which the user can select different inputs for simulating wildfire behaviour, from the duration of the event to the selection of different meteorological variables (wind, fuel moisture). The model gives an estimation of the wildfire perimeter for each hour of the simulated event based on the vegetation cover, the slope, and the boundary conditions previously given by the user. The output is probabilistic, and easily integrable into a risk / hazard assessment. It is also possible to study the effect of fire-fighting actions to have more realistic results and high-fidelity reanalysis of past events.

The model has been provided, along with RISICO and myDEWETRA.world to PPRD East 3 Member States and its outputs can be used to understand the dynamics of a wildfire which is a fundamental aspect of building a reliable and realistic scenario.

Each simulation of PROPAGATOR needs the following information to be specified by the user:

- Ignition point;
- Date and time of scenario - name of simulated scenario;
- Synoptic wind conditions (direction and magnitude) for given scenario;
- Synoptic FFMC conditions for the given scenario (it can be retrieved for forecast scenario with a dedicated run of RISICO)
- Eventual firefighting actions (e.g., waterlines, fuel removal by heavy vehicle actions…) represented as point or lines at a given time.

Each simulation gives out:

- Hourly probability map of wildfire spread probability for all the simulated time window;
- Iso-chrones of fire propagation; a line each hour which encompasses all cells with a probability higher than 0.75 of being reached by the wildfire

advance. This output transforms a raster output (fire arrival probability field) to a vector one (perimeter of fire according to a certain threshold).

4. Early Warnings for Wildfire Risk

As highlighted by the EWS checklist (UNDRR, 2018), at the heart of an early warning system there are warning services, which require a solid scientific foundation and reliable technology for real-time hazard monitoring and forecasting. These services operate around the clock, every day of the year, and must be staffed by qualified personnel. In fact, continuous monitoring of hazard parameters and their precursor is essential for timely and accurate warnings, allowing affected communities to enact appropriate disaster management plans.

This chapter gives a general introduction of the models that can assist into wildfire danger forecasts, with a focus on models and data presented during PPRD East 3. It also outlines the general steps necessary to produce an effective early warning bulletin, by combining different sources of data and information. The typical steps are explained and complemented with an example of a routine that utilizes models and data available on the myDEWETRA.world platform. Appendix 2 explores in more detail the use of the available layers for fire forecasting on the myDEWETRA.world platform.

4.1. Forecast Models

This section provides an overview of state-of-the-art wildfire forecasting models, their outputs, and possible uses in the evaluation of wildfire danger indexes.

4.1.1. Weather models for wildfire risk

The input of forecast models for wildfire can be divided in two macro categories:

- Dynamic data: temperature, rainfall, humidity, hot spot, intensity, and direction of wind
- Static data: slope, aspect, fire susceptibility maps, vegetation index, historical data, etc

Numerical Weather Prediction (NWP) models are the primary sources for dynamic data, as they are used for weather forecasting and researching weather and climate processes. Improvements in these models, and a vast increase in the observation data that feeds them, have made it possible to provide accurate and reliable meteorological information for future times at given locations and altitudes.

Modern wildfire forecast models use the outputs of weather model as their inputs.

Higher resolution weather datasets can offer more precise information for the evaluation of wildfire danger. This aspect is very relevant when thinking about orography and landcover.

4.1.2. The European Forest Fire Information System (EFFIS)

The European Forest Fire Information System (EFFIS) consists of a modular web geographic information system that provides near real-time and historical information on forest fires and forest fire regimes in the European, Middle Eastern and North

African regions. Fire monitoring in EFFIS comprises the full fire cycle, providing information on the pre-fire conditions and assessing post-fire damages.

EFFIS has been established by the European Commission (EC) in collaboration with the national fire administrations to support the services in charge of the protection of forests against fires in the EU and neighbouring countries, and also to provide the EC services and the European Parliament with harmonized information on forest fires in Europe.

Since 1998, EFFIS is supported by a network of experts from the countries in what is called the Expert Group on Forest Fires, which is registered under the Secretariat General of the European Commission. Currently, this group consists of experts from 43 countries in European, Middle East and North African countries.

EFFIS includes, starting from the pre-fire state, the following modules:

1. Fire Danger Assessment,
2. Rapid Damage Assessment, which includes
    - (2.1) Active fire detection
    - (2.2.) Fire severity assessment and
    - (2.3.) Land cover damage assessment,
3. Emissions Assessment and Smoke Dispersion,
4. Potential Soil Loss Assessment, and
5. Vegetation Regeneration.

Additionally, another EFFIS module supporting fire monitoring is the Fire News module, which geo-locates all the news related to forest fires that are published on the internet in any of the European languages.

Near-real time information on the first two modules mentioned above is provided through the so-called "current situation" viewer.

At the core of EFFIS lies the so-called Fire Database, which includes detailed information of individual fire records provided by the EFFIS network countries. Currently data in the database comprises nearly 2 million records provided by 22 countries. Information on the data in the database is provided through the fire history application of EFFIS.

Of particular interest to this guideline, among the rest, EFFIS publishes two indicators that provide information on the local/temporal variability of the Fire Weather Index (FWI) compared to a historical series of approximately 30 years. These indicators are

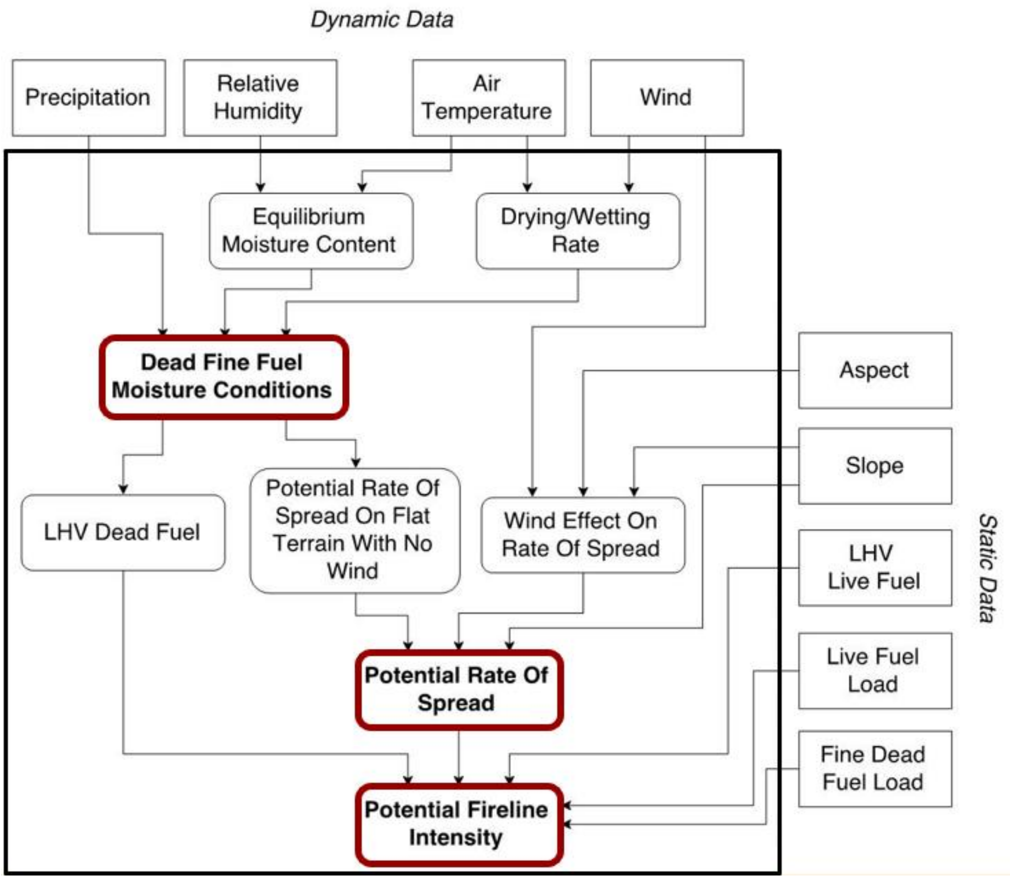
- The ranking, corresponding to the percentiles of occurrence of FWI
- The anomaly, computed as a standard deviation from the 30-year historical mean values of the FWI.

Different Fire Danger Classes are defined (Very Low, Low, Moderate, High, Very High and Extreme) with a Very Extreme Fire Danger Class introduced in June 2021 to provide discrimination about the level of fire danger in extensive areas that were initially classified at "Extreme" Fire Danger in the Mediterranean region during the summer months.

4.1.3. RISICO – Fire danger rating system

The conceptual scheme and architecture of the RIS.I.CO. system (Fiorucci et al., 2008; Fiorucci et al., 2011) originated in the early 2000s. Since 2003 the system has been used operationally by the Italian Department of Civil protection. The conceptual scheme is common to other regional scale-based systems. The basic principles are common to those introduced in the late 80s by Canadian researchers who developed the Fire Weather Index (Van Wagner and Pickett, 1985) within the more Canadian Forest Fire Danger complex Rating System. This system, purely meteorological, has been widely modified to be responsive to the fuel cover, adapting it to the national reality and in general to the Mediterranean countries.

In the following flow chart, there are the inputs to the forecast model divided in dynamic and static data and the results of the model in red boxes.



The outputs of the forecast model are:

- Potential Fireline intensity [kW/m],

- Moisture content of fine fuel (humidity of necromass) [%],
- Rate of Spread – RoS (rate of propagation) [m/h],
- Rate of Spread – RoS (PPF) (rate of propagation corrected by a static susceptibility layer to reduce danger in not fire prone areas) [m/h],
- Effect of wind on RoS (contribution of the wind on the speed of propagation, a factor of the RoS formula) [dimensionless],

The output of this forecast model is available every three hours starting with the first midnight run. For instance, the run of the 00:00 of the day 8th July 2022 contains the forecast from +3 hours (03:00 8th July 2022) to +216 hours (00:00 17th July 2022). For each simulation there are 17 layers.

Figure 2 shows the rate of spread in m/h for the 17th of July 2022 based on the forecast run 8th July 2022.

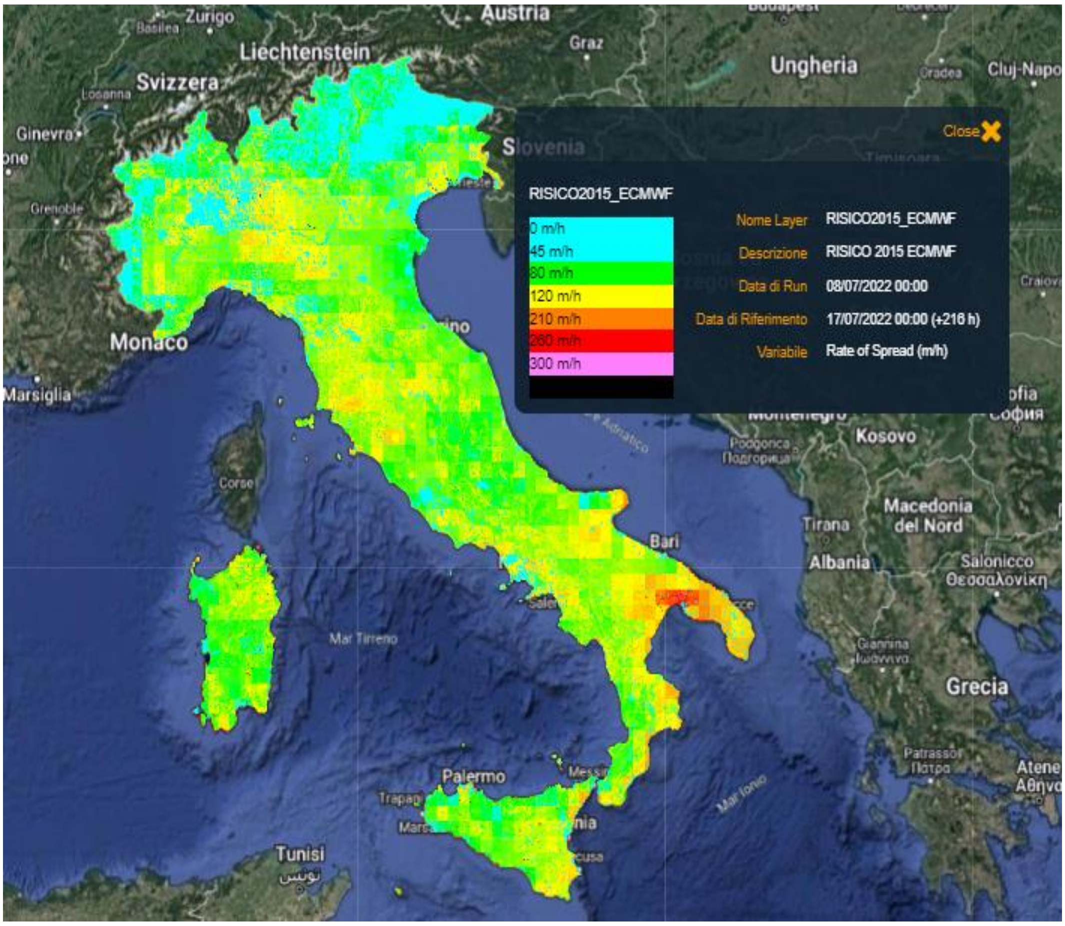


Figure 2: rate of spread in m/h for the 17th of July 2022 based on the forecast run 8th July 2022

The native output of RISICO Model is a set of raster layers giving information pixel by pixel at the given analysis resolution.

In order to be able to provide an interpretation of the situation, it is necessary to aggregate the data on a spatial scale. The FDI (Fire Danger Index) is a spatial and temporal aggregation of RISICO's outputs. The spatial aggregation is made on a regional level and the temporal aggregation on a daily basis. To aggregate the data, all points above a certain threshold are taken.

Figure 3 shows the FDI for Italy regions for 75th percentile mean rate of spread (PPF).

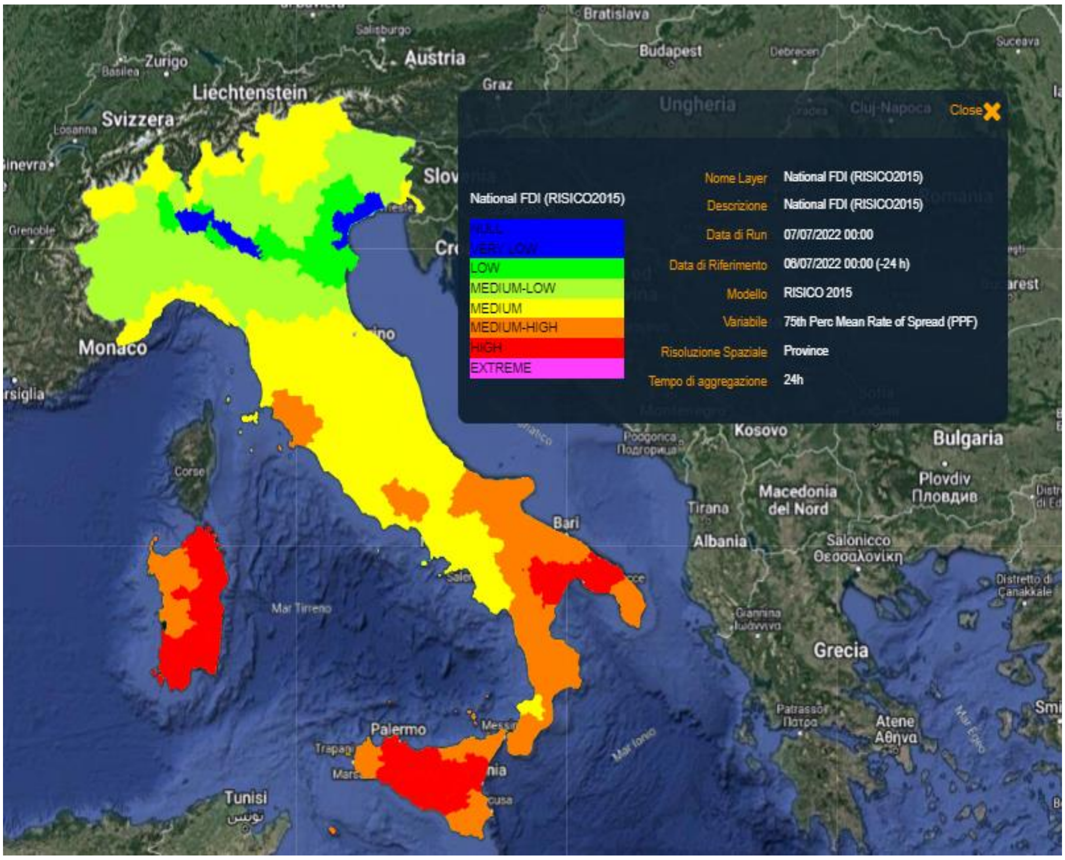


Figure 3: FDI for Italy regions for 75th percentile mean rate of spread (PPF).

4.2. The National wildfire danger bulletin

A national wildfire danger bulletin is a critical communication tool used to inform relevant stakeholders and often also the public about the current and forecasted fire danger levels across different regions of a country. Typically issued by LEMAs based on information from Hydrometeorological Centers, this bulletin can provide essential information on the likelihood of wildfire occurrences and potential fire behaviour. It may also include operational recommendations and necessary precautions to prevent fire outbreaks and ensure public safety.

Fire danger bulletins are typically based on comprehensive analyses of various environmental factors, including weather conditions, fuel moisture, and ongoing and past fires. By integrating data from sources such as NWP models, fire forecasts models, satellite imagery, and ground observations (including also data from automated monitoring network or from assessment teams that monitor areas at risk), these bulletins offer a detailed and accurate assessment of fire risks. The information is often presented through color-coded maps, indices, and specific advisories that highlight areas, for example, of high, moderate, or low fire danger.

The primary goal of a national wildfire danger bulletin is to enhance preparedness and response strategies for wildfire events. By providing timely and actionable information, these bulletins help to coordinate firefighting efforts, guide public behaviour during high-risk periods, and ultimately reduce the impact of wildfires on communities and natural resources.

Operationally, the process of creating a national wildfire danger bulletin involves four main steps:

- Forecasting phase: Acquiring data from weather numerical models to feed fire danger models and create meteorological awareness.
- Evaluation phases: Assessing and evaluating data to determine potential fire risks.
- Drafting phase: Preparing the bulletin with the assessed information, including maps, indices, and advisories.
- Operational phase: Distributing the bulletin and implementing recommended precautions and actions.

Here, we present a routine example for the production of a national wildfire bulletin, also including the tools and elements provided by the PPRD East 3 programme and discussed with the programme countries. This example highlights the activities typically performed during each step, including the estimated times and potential stakeholders involved in the process. These elements are indicative and aim to provide a general overview of the entire creation process, which should be adapted to fit national regulations and frameworks.

4.2.1. Creation of the bulletin – Weather Forecasting phase

The first step for creating the national wildfire danger bulletin starts with situational meteorological awareness. All the information gathered from NWP models and current weather conditions are used for a comprehensive picture of the current meteorological situation.

TIME (24H FORMAT DATA)	ACTION	WHO
10:00	Start of the hydrometeorological routine	Hydrometeorological forecasting center

Between 10:00 – 12:00	Meteorological situation awareness	
	Send the meteorological situation awareness	

Table 5: Weather Forecasting Phase for the creation of the national wildfire danger bulletin

4.2.2. Creation of the bulletin – Evaluation phase

During the evaluation phase, activities combine meteorological information with direct or indirect observations/monitoring (e.g., via satellite) of active or ongoing fire. These data, in conjunction with outputs from the RISICO model, are used to generate the national wildfire danger bulletin.

TIME (24H FORMAT DATA)	ACTION	WHO
12:00	Start of the evaluation phase	Forestry agency and line ministries
Between 12:00 – 13:00	Wildfire situational awareness	
	Send the wildfire situational awareness to LEMA	
	First evaluation of the fire danger forecasting model (RISICO)	Local Emergency Management Agency

Table 6: Evaluation Phase for the creation of the national wildfire danger bulletin

The evaluation of fire danger forecasting model can be done by using the "*RISICO Model*" available on the myDEWETRA.world web-GIS platform.

Outputs from RISICO Model can be discretized in different classes, based on thresholds that can be fully customized and tailored by each Country.

4.2.2.1. Classification and aggregation of thresholds

Here, an example of the parameter "rate of speed" in native value and the possible classification in thresholds. Such a classification could be useful to understand how the fire can be spread if an event occurs in a known area.

RISICO rate of speed [m/h] native value	PROPOSED THRESHOLDS
0 [m/h]	Very Low
45 [m/h]	Low

80 [m/h]	Medium
120 [m/h]	Medium – High
210 [m/h]	High
260 [m/h]	Very High
300 [m/h]	Extreme

Table 7: Rate of Spread values used to classify the fire danger. Thresholds defined to have 7 classes, from very low to extreme fire danger

These RISICO model thresholds can be automatically linked to a colour coding system that indicates different wildfire risk values (increasing alert levels). Each colour would then correspond to a distinct level of activation of the civil protection system required to manage the risk. Also in this case, the association could be fully customized and tailored by each Country.

Here, an example of aggregation of threshold using colour coding.

RISICO THRESHOLDS	COLOUR CODING	RISK
From Very Low to Low	Green	Very Low Risk = R1
From Medium to Medium – High	Yellow	Low Risk = R2
High	Orange	Medium Risk = R3
From Very High to Extreme	Red	High Risk = R4

Table 8: Colour coding application. RISICO model thresholds can be automatically linked to a colour coding system corresponding to increasing levels of alert

4.2.3. Creation of the bulletin – Drafting phase

In the drafting phase, the duty officer/operator compiles the bulletin. All the information gathered during the evaluation phase needs to be summarized and included in the bulletin. This phase involves multiple steps to ensure accuracy and comprehensiveness.

TIME (24H FORMAT DATA)	ACTION	WHO
13:00	Drafting of the national wildfire danger bulletin	Local Emergency Management Agency
Between 13:00 – 14:00	The duty officer checks different wildfire risk models, gathers information in order to confirm or change the semi-automated	

	compilation of the RISICO output models.	

Table 9: Drafting Phase for the creation of the national wildfire danger bulletin

The duty officer/operator reviews the semi-automated outputs from the RISICO model, integrating additional insights from other fire forecast models (such as EFFIS or the national fire model), and considers ongoing wildfire events and field information. This expert judgment ensures that the bulletin reflects the most accurate and up-to-date fire danger assessments In addition to technical data, the bulletin should also include practical advice and recommended actions for various stakeholders, from local authorities to the general public. This might involve specifying areas where fire restrictions are necessary, advising on evacuation plans, or recommending specific firefighting resources to be on standby.

TIME (24H FORMAT DATA)	ACTION	WHO
14:00	Issuance of the national wildfire danger bulletin	Local Emergency Management Agency
	Dissemination of the national fire danger bulletin	

Table 10: Dissemination Phase for the creation of the national fire danger bulletin

The PPRD East 3 programme has provided a tool that precompiles the model into a country tailored bulletin. This will facilitate and expedite the whole process. However, no EWS should be bond to an application or platform, the most important thing is to define the entire process and, only then, provide adequate tools to support it.

4.2.4. Dissemination of the bulletin – Operational phase

The operational phase encompasses various activities aimed at managing wildfires, ranging from the distributing the wildfire danger bulletin, to checking available operators/personnel, and ultimately deploying firefighters/rescue teams for response efforts.

Regarding the dissemination of the wildfire danger bulletin, the distribution list can be diversified according to the stakeholders involved in the process. An example of receivers of the bulletin may be divided in national, regional and local stakeholders that have different activities to do according to their own competence:

- Municipalities and local sections of LEMA
- Firefighters
- CSO and Volunteering organization
- Other branch of Local Emergency Management Agency (such as logistics, COMMs, etc.)
- Media and COMMs agency

Every stakeholder at any territorial level must have their own operational phase to be activate in order to support the entire civil protection system.

4.2.5. Information and communication of population – Operational phase

One of the key objectives of an emergency plan is to define all the necessary resources and protocols to effectively communicate to the population the necessary actions and behavioural codes to be followed during an emergency.

The following points should be defined:

- Existing means of information
- List of the media channels used Municipalities and local sections of LEMA to disseminate information to the population.
- Detail timings (who does what and precisely at what time?) and contents (what is the content of the message? Including informing the population on how to act on the warnings) of warnings.
- Explanation of how population is informed, official channels, media, etc.

5. Early Warning communication and Interagency coordination

As defined earlier in this guideline, several stakeholders are involved in the EWS. Most of these stakeholders are governmental agencies which implies that interagency coordination needs to be considered throughout the whole process of early warning.

One of the first and most important parts in order to establish effective EWS is to identify the stakeholders, their functions, roles and responsibilities for each stage of the process. Once identified, the results be defined and documented in legislation, polices, strategies and plans. The legal framework should remove the uncertainty and misunderstandings of responsibilities. Furthermore, a sound regulatory framework should also determine the coordination mechanism.

More details about some specific aspects on coordination with the EU civil protection mechanism can be found in the "*Guideline for duty offices: Activation of and requests for assistance via the EU civil protection mechanism*" provided by the PPRD East 3 programme.

5.2. Coordination Mechanism

The coordination mechanism should promote that collaboration is established at an early stage, that trust is built between stakeholders and that collaboration is established in day-to-day practice. Coordination can be done in several different ways and needs to be country tailored. However, the methods for collaboration and coordination needs to be described and agreed upon. The use of a common language will facilitate the collaboration. To facilitate the coordination further a predefine and well-known primary contact point is used in many organisations. This can for example be a duty officer. The contact point receives/communicates alerts and other information. It ensures that the correct recipient is reached in the organisation and maintains contact information to other actors in the EWS.

Information sharing between different stakeholders in the EWS is a prerequisite for well-founded decisions. Common approaches to information sharing that are sustainable over time and independent of technology is the greatest success factor. Furthermore, it is important to have high level of availability and good communication capability by all stakeholders involved and to seek and convey information.

Stakeholders involved in the EWS need to have the ability to create common operational picture and have a common understanding of what is done when and by whom. Standard operational procedures can be used to visualize the processes.

5.3. Communication

During all parts of early warning to early action is communication an important element to consider. It needs to be strategic communication that aims to create common ground for the coordination. Coordinated communication, at the right time, both with in agencies and between agencies strengthens the collaboration. Interagency coordination is also needed to ensure the delivery of consistent messages by multiple agencies within impact-based forecasting and warning systems. Therefore, warning communication strategies should be in place at the national, regional and local levels, to ensure coordination across warning issuers and dissemination channels.

On a national level one planning document that is especially relevant to EWS is the National Emergency Telecommunication Plan. A strategic plan that ensures communication availability during all phases of a disaster, by promoting coordination across all levels of governmental institutions, between public and private organisations and within communities at risk.

6. Integration of EWEA strategies

Early actions in disaster management are crucial for reducing potential impacts and ensuring community safety. Central to this approach is the understanding and acknowledgment of risks by individuals and key actors, coupled with adherence to national warning services and preparedness initiatives.

When an early warning is issued, it must trigger a coordinated response from authorities at relevant territorial levels, business, communities and other stakeholders. In particular, early warnings must activate emergency response plans promptly with the aim of mitigating the hazard's impact on people, assets, and the environment.

To translate early warnings into actions, protocols and plans need to be developed to implement preventive measures based on the received early warning. These plans, developed collaboratively and widely shared, should specify how warnings are disseminated and outline actions to be taken. They are essential for readiness across different vulnerabilities and ensuring effective communication during emergencies.

Moreover, education and preparedness programs play a pivotal role in equipping communities with the knowledge and skills needed to respond effectively to warning messages. This includes, among all, practicing evacuation strategies integrated into comprehensive disaster management plans, as well as organizing exercises and drills to let all the actors familiarize with the EWEA strategies.

It is clear, therefore, that a through civil protection planning is fundamental to ensure an effective integration of EWEA strategies at all levels.

This chapter illustrates only how civil protection actors can be progressively activated based on various alert levels. Additionally, it outlines potential preventive measures that can be implemented before a wildfire begins.

For further details on preparedness and planning, please refer to the "*Guidelines on civil protection planning*" developed within PPRD East 3.
Overall, linking early warning to early actions require several elements. The document "*Establishing effective links between early warnings and early action: general criteria for floods*", produced in the framework of IPA FF programme, offers valuable direction to operationally develop such a system.

6.1. Activation of operational phases

Given the forecasted danger/alert level provided by the bulletin, the preparedness and the response phase can be articulated into different operational phases:

• Attention phase: All measures on first notification or information on an emergency and serves as a signal to increase readiness.

• Pre-Alarm phase: Readiness of all post notification measures or information that an emergency or disaster is imminent or has started.

• Alarm phase. Activation arises when an emergency has occurred.

Here, an example of the whole process of linking hazard information to preparedness and response actions, marking the transition from early warning to early action.

RISICO THRESHOLDS	COLOUR CODING	MINIMUM ACTIVATION OF OPERATIVE PHASES	IN CASE OF WILDFIRE EVENT
From Very Low to Low	Green	No operative phases needed to be activated/monitoring the situation	Alarm phase **must be activated***
From Medium to Medium – High	Yellow	Attention phase	
High	Orange	Pre-alarm phase	
From Very High to Extreme	Red		

Table 11: Process to ink hazard information (Risico Thresholds and alert levels) to preparedness and response actions (Operational Phases)

*NOTE: The Alarm phase can be activated only in case of a wildfire event.

Each alert phase activates specific operative procedures within the Civil Protection system. The emergency plans require to develop standard operative procedures to be enacted at each level.

6.1.1. Preventive measures based upon the National Wildfire Bulletin

Operational phases entail a progressive mobilization of resources and personnel on the ground to ensure a prompt and efficient activation of the system according to the level of alert that is provided by the bulletin. This means that a set of preventive measures can be defined and implemented upon receiving the national bulletin, and before the outbreak of a forest fire, depending on the specific operational phase that is enforced. These can comprise precaution/preventive measures to minimise dangerous behaviours in hot spot areas, or the preventive positioning of personnel and vehicles in strategic regions. Such measures involve not only local-regional authorities and firefighting personnel, but also forecasters, each of the involved institution, volunteer corps, and civil population.

In case of critical situation predicted for the current and following days, forecasters, according to their mandate, can intensify the frequency of situation evaluation to guarantee high frequency updates if the need arises. This can also include monitoring satellite observation products with increased frequency, checking the trend of weather variables from weather stations networks and NWPs, and checking wireless networks of sensors / cameras / drones output in sensitive areas, when this technology is in place and according to their respective mandate.

To provide a few examples of preventive measures, Authorities may close public parks, campgrounds, hiking trails, or other outdoor recreational areas where the risk of fire ignition and its fast spread is high. This could be put in practice to prevent accidental fires caused by human activities, such as campfires or discarded cigarettes. Temporary bans on outdoor burning can also constitute a preventive measure connected to the information provided by a wildfire danger bulletin. Open burning, including bonfires, campfires, and backyard burning, may in fact be prohibited during periods of high wildfire risk, also in this case to minimize the potential for fast/intense fires to escape control. Population can be invited to clear vegetation, dead leaves, and other combustible materials from around properties to create a safe buffer zone around houses and buildings.

In terms of preparedness, firefighting personnel can be strategically deployed, ensuring their presence in high-risk areas. Additionally, their equipment should be thoroughly inspected and reviewed to guarantee optimal functionality. Water tanks should be promptly filled, ensuring an adequate and readily available water supply for firefighting operations.

One crucial anticipatory action is the active monitoring of the territory to detect wildfires at an early stage, particularly in areas where a high to extreme fire danger level is forecasted. Such activity, which can be foreseen also in ordinary conditions according to seasonal plans, should be enhanced when a warning for wildfire danger is issued.

However, patrolling for wildfires can be a difficult task for firefighters due to the size of the areas that need to be monitored. To ensure an early detection of wildfires various methods can be used, including the involvement of assessment teams, also composed by trained volunteers, that can be activated starting from the attention phase (see the flow chart), as well as the deployment of unmanned aerial vehicles (UAVs).

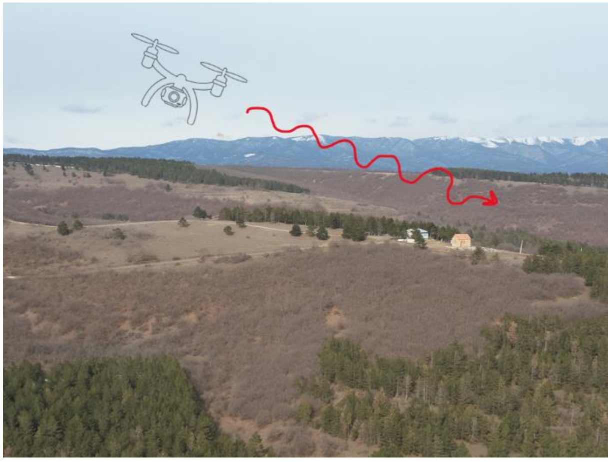


Figure 4: UAVs can reach remote and dangerous areas potentially exposed to wildfires.

UAVs are particularly valuable when access to certain areas is hindered by dense tree cover or when fires might occur in hilly and mountainous regions. Additionally, UAVs equipped with thermal imaging cameras can detect fire outbreaks even at night.

Apart from their role in detecting ignition points and wildfires, UAVs can serve other purposes, such as collecting data for fire evolution monitoring. They, indeed, can provide valuable information for fire simulators such as PROPAGATOR (Trucchia et al. 2020), that allows to represent the possible spread of fire on the territory, starting from a point of ignition and forecasts for wind speed, direction, fuel moisture content.

Overall, these preventive measures need to be defined through specific SOPs. In particular, in the case of active monitoring by the means of UAVs, SOPs are required to operate UAVs, activate and coordinate fleets and to define communication modalities.

6.1.2. Situational awareness during fire extinguishment actions

During fire extinguishment actions, UAVs can be deployed to provide situational awareness, supporting emergency services and chief of firefighting operations in managing the emergency. Trained firefighters can control UAVs to gather crucial information at various stages of their missions. For instance, UAVs can fulfil the following tasks:

- Support Search and Rescue (SAR) activities by enabling responders to remotely detect and identify persons, assess the situation to determine the number of people to rescue, estimate the time needed to reach them, evaluate the level of danger to which they are exposed and plan evacuation strategies.
- Provide information of areas to priorities for firefighters and to inform decision on the ground, such as near-real time data for rapid mapping and for regular updates of fire evolution,
- manage fire extinguishing operations in an emergency situation, by supporting chief of firefighting operations to assess and plan extinction activities. In this regard, infrared (thermal) imagery is crucial to detect high heating areas, even in the presence of smoke, offering technical insights beyond human capabilities.
- Moreover, they can be used in dangerous areas eliminating the need to expose first responders to potential harm.

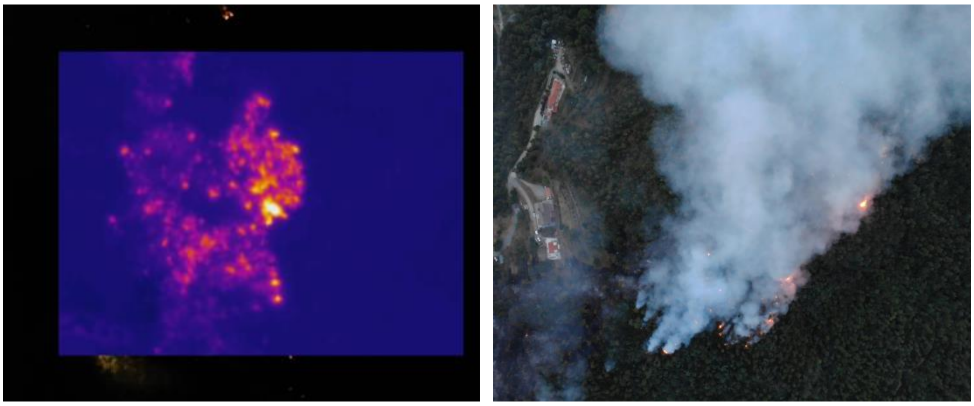
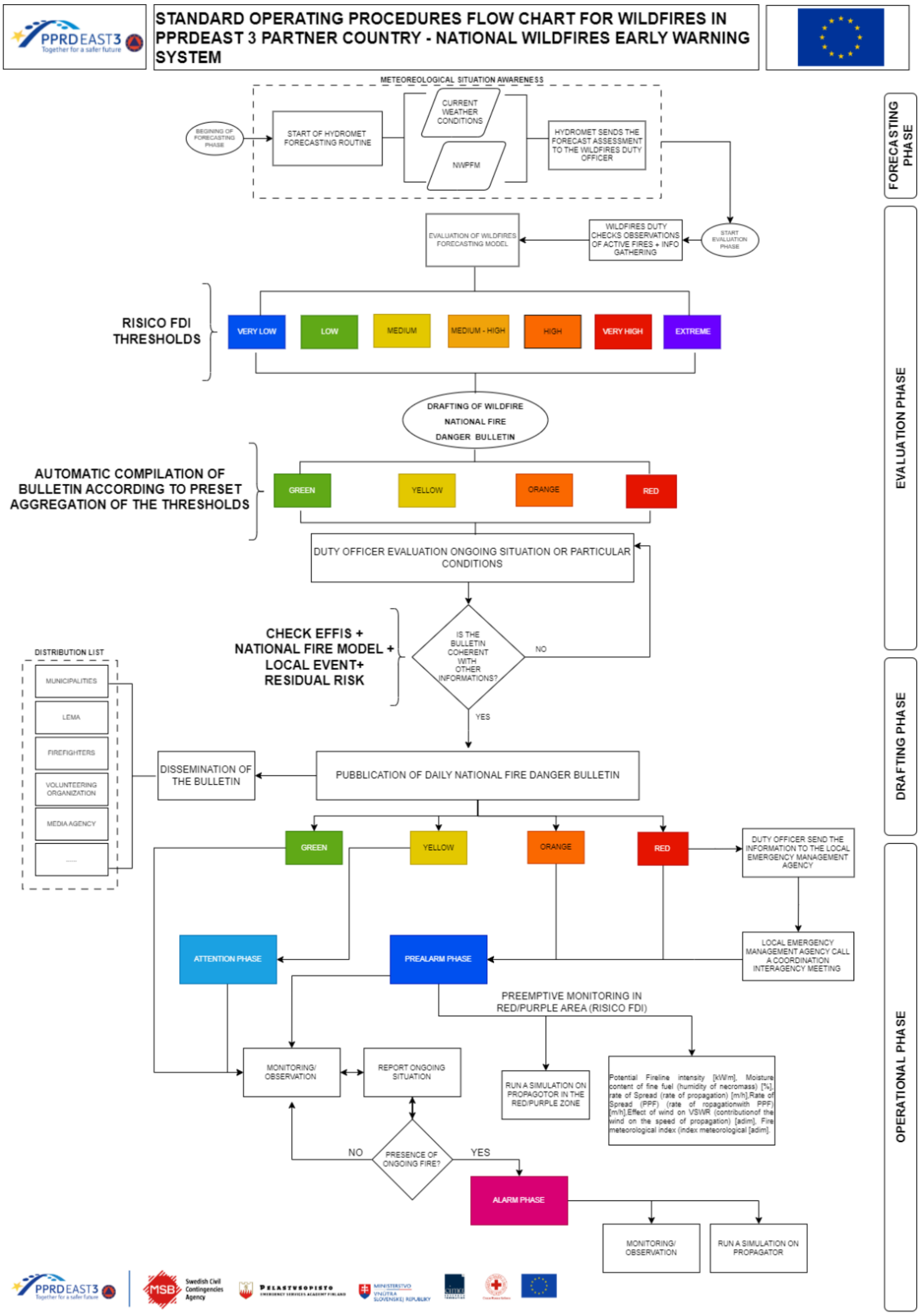


Figure 5: Left: heat areas detected through thermal cameras. Right: smoke can hinder the vision during fire.

It is also possible to guide fire-fighting actions by employing simulations of the fire-line evolution or the effect of fuel removal (or other firefighting actions) through wildfire spread such as PROPAGATOR or similar software, when outputs are furnished to personnel in charge in a timely manner. Fire front can be simulated not only from the ignition, but also from an intermediate stage, e.g., starting from the latest shape of fire front retrieved by UAV means. Fast simulation of potential fire spread can also be enhanced by using accurate weather conditions for wind speed and direction, provided by portable weather stations.

6.2. Examples of flow charts

This is a depiction of the general decision-making process and interagency coordination involved in the process of issuing and disseminating the national wildfire bulletin and the subsequent activation of operational phases within emergency management plans also known as Anticipatory Actions.



ANNEX 1: Disaster Loss Database for wildfires

Disaster loss databases are useful tools because they provide valuable information on the impact of natural disasters, such as earthquakes, hurricanes, floods, and wildfires. By analyzing past events and their associated losses, researchers and policymakers can better understand the patterns and trends of disasters and develop more effective strategies for reducing their impact on communities. Such databases can also help with planning for disaster response and recovery efforts.

Keeping records of past wildfire events is a good practice in wildfire hazard management because it provides valuable information about the frequency, severity, and location of wildfires. This information can be used to identify areas that are at high risk of wildfire and to develop more effective wildfire prevention and response strategies. It can also help with post-fire recovery efforts, such as identifying areas that need reforestation or erosion control.

In the framework of PPRDE3 hazard mapping, a comprehensive spatial databases of past fires is used to build a susceptibility map (Tonini et al., 2020; Trucchia et al., 2022a, 2022b). Susceptibility maps can be used to model the wildfire likelihood of different zones of the analysed area due to the intrinsic characteristic of the territory. When information on type and characteristics of vegetational fuel is provided, susceptibility maps can be upgraded to hazard maps (Trucchia et al, 2023) in order to spot the areas where intense fires, difficult to control, can happen in the future years.

Modern GIS technology is useful in tracking the date, shape, and other metadata of each fire occurrence, including start and end dates, response of firefighters, and coordinates of the ignition point. This information can be used to create detailed maps of fire activity, which can help with identifying areas that are at high risk of wildfire, analyzing patterns and trends of wildfires over time, and evaluating the effectiveness of wildfire management strategies. By using modern GIS technology, researchers and policymakers can make more informed decisions about wildfire prevention and response efforts, which can ultimately save lives and protect communities.

- **Example of geodatabase**

Standard practice in establishing wildfire databases uses Shapefile or GeoJson format.

Each fire is represented by a polygon. The shape of the poligon can be obtained via Earth Observation techniques or retrieved by ground. Each polygon is associated to a series of fields (that is, associated data). In the database, the polygon of a single wildfire and its associated fields form a row of the matrix representation. In the following, a list of possible field to be associated to the wildfire polygon:

- Wildfire date (it can also be divided into start and end date); Better if the dates are in standard format. If also the hours are
- Wildfire ignition point (if available)
- Wildfire type (e.g. pasture fire, forest fire, bushfire…)
- Information about type of response (e.g. heavy response, moderate response, aerial means, waterlines...)

- **Example of Ligurian Shapefile from Geoportale Regione Liguria**

Geoportale Regione Liguria (https://geoportal.regione.liguria.it/) is an online platform provided by the Regional Government of Liguria, Italy that provides access to geographic information and data about the region. It includes a variety of information, such as maps, satellite imagery, aerial photos, and environmental data.

One of the features of the Geoportale is the availability of yearly updates on shapefiles of burned areas in the region. These shapefiles are created based on satellite imagery and other sources, and provide detailed information about the extent and location of areas that have been affected by wildfires.

This information can be used as a disaster loss database because it provides valuable data about the impact of wildfires in the region over time. By analyzing the yearly updates of the burned area shapefiles, researchers and policymakers can better understand the patterns and trends of wildfires in the region and develop more effective strategies for reducing their impact on communities.

In the provided example (which has been downloaded by the Geoportale), a single wildfire event is sometimes divided into several shapefiles, due to a different classification of sub-regions of the burned area. For example, a single fire could have spanned over pastures and woodland, and thus two sub polygons are provided. Such polygons can then be processed via GIS techniques merging them into a single shapefile per wildfire event.

- **Example of shapefiles: year 2019 of Ligurian Wildfires**

Figure 6: Municipalities of Liguria Region, NW Italy, with the green shapes representing wildfires which took place in year 2019, Source: Geoportale of Liguria Region

Name of file	Data	Year	Scope
Incendi_2018	Wildfires Shapefile	2018	Liguria (Italy)
Incendi_2019	Wildfires Shapefile	2019	Liguria (Italy)
Incendi_2020	Wildfires Shapefile	2020	Liguria (Italy)
Incendi_2021	Wildfires Shapefile	2021	Liguria (Italy)

Table 12: Example of wildfire dataset provided by Geoportale of Liguria Region

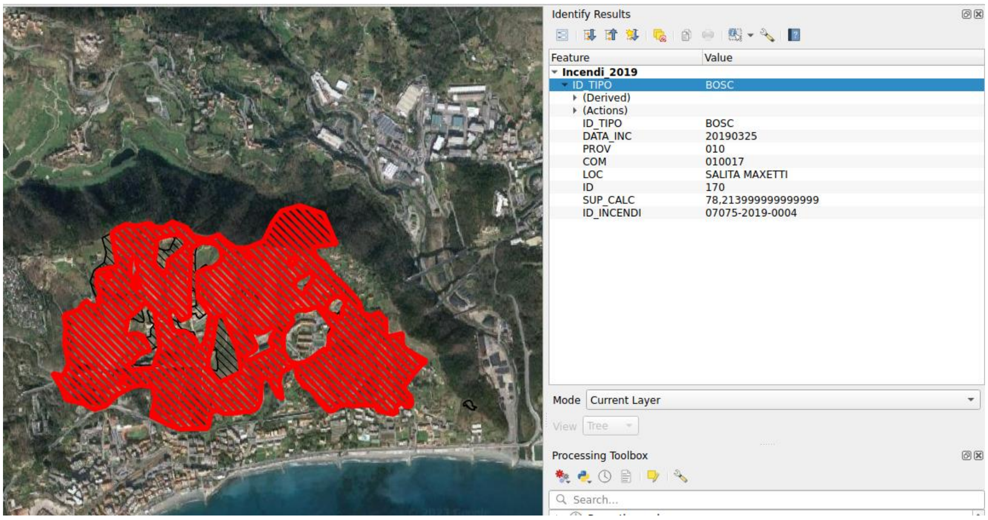


Figure 7: Example of Wildfire with the following fields: ID_TIPO (that is, type of fire: woodland, shrubland, pasture, urban, etc.), DATA_INC, that is, the date of the fire start, PROV COM, LOC and ID represent respectively the province, municipality and neighbourhood and municipality code. SUP_CALC is the total burned area in hectares, and ID_INCENDI is the ID of the fire in the regional indexation. Source: Data downloaded from geoportale Regione Liguria and visualised in QGIS

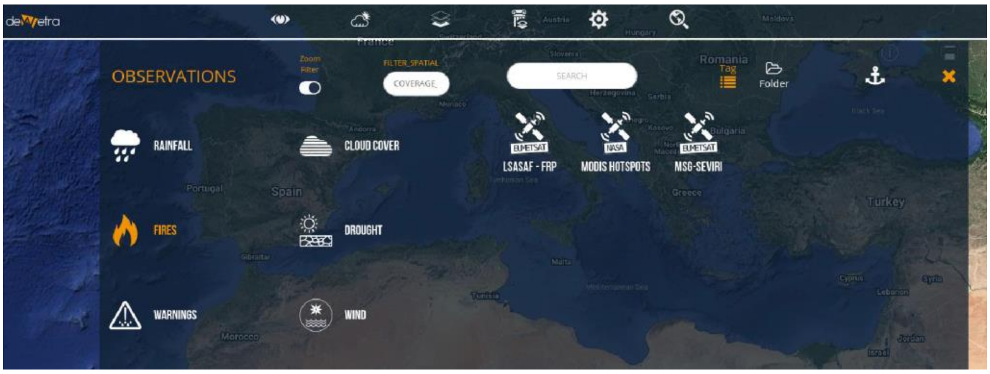
See Database_Annex1.zip for a sample of the dataset described in the Annex.

ANNEX 2: Example of wildfire danger forecast routine

The following presents an example of a wildfire danger forecast routine using global tools. Specifically, it utilizes myDEWETRA.world with global layers such as RISICO WORLD and EFFIS - GWIS current situation visualizers.

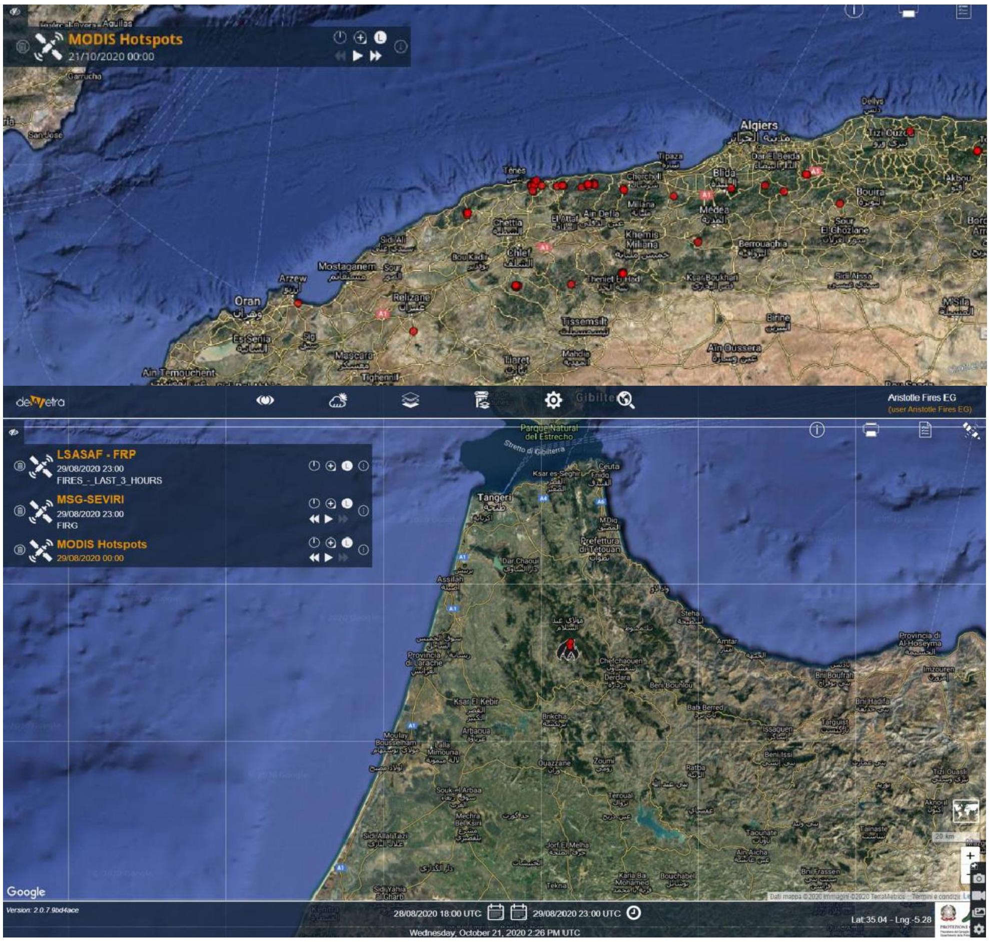
National-scale tools provided by PPRD East 3 to the programme countries (including custom RISICO installations, hazard maps, etc.) will seamlessly integrate into this general framework.

PHASE 1: ACTIVE FOREST FIRE MONITORING



By using the OBSERVATION module of myDEWETRA.world, ongoing fires can be identified and monitored. Three tools are available when clicking on the FIRES button.

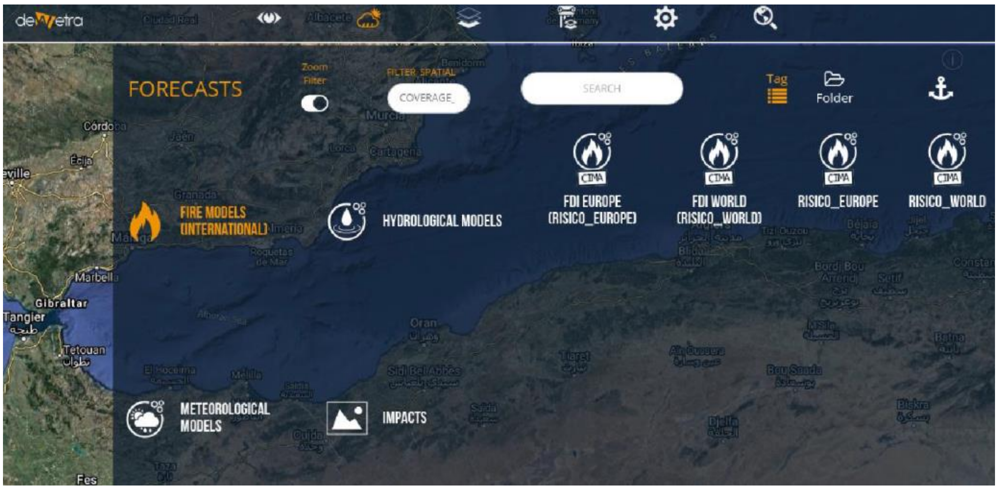
The advised order of analysis is the following: i) Modis Hotspots – 2) LSASAF FRP – 3) MSG SEVIRI. For what concerns MODIS hotspots, they are often grouped into coloured balloons. By clicking on each balloon, you will zoom to the desired area with a finer representation of the MODIS HOTSPOTS.



The monitoring activity can be also carried out making use of the EFFIS platform (https://effis.jrc.ec.europa.eu). Thanks to such platform, it is possible to check active fires and burnt areas (MODIS and VIIRS) from Current Situation Viewer of Effis, Copernicus Emergency Management Service (https://effis.jrc.ec.europa.eu/static/effis_current_situation/public/index.html).

PHASE 2: FIRE DANGER FORECASTS

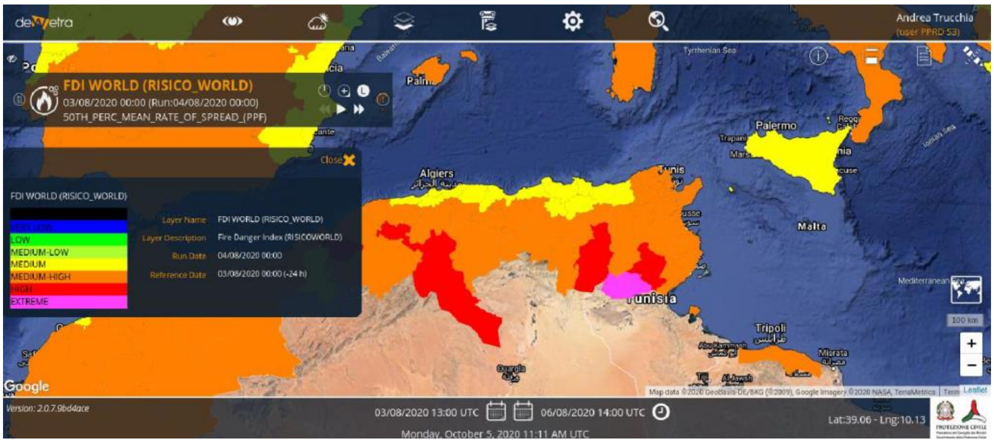
To forecast the potential occurrence of large-scale wildfires, we can select one or more forecasting models by clicking on FORECAST on the top banner, and then on FIRE MODELS (INTERNATIONAL). We shall concentrate on two models, the FDI WORLD and RISICO WORLD. The first gives out data which is aggregated in space and time, while the second one will give as output time averaged layers or three hourly updated layers.



AGGREGATED ANALYSIS WITH RISICO FDI WORLD

On myDEWETRA.world, check FDI World - Daily 50% mean rate of spread

- If red zones or purple zones are spotted in this layer, it may already constitute a proxy for wildfire hazard.
- Orange areas also need to be investigated using further analysis, e.g. the effect of wind on rate of spread RISICO World – Effect of wind on RoS.



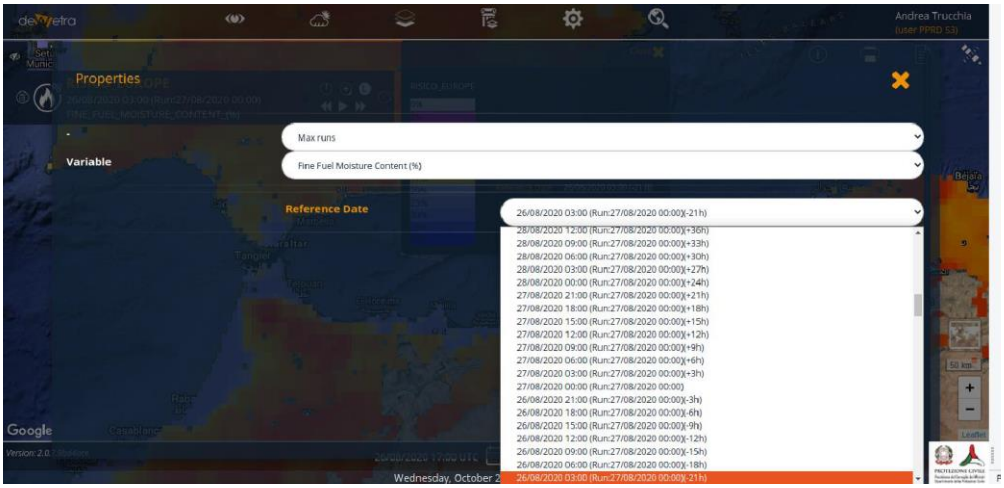
RISICO FDI World aggregates hourly maps of rate of spread in time, over 24 hours, and in space, according to NUTS2 regions. Mathematical averages (mean) and percentile-based aggregators are also available. Red and purple areas identify those regions affected by persistent critical moisture conditions and wind.

In the following, pixel-wise models (that is, pixels that are not aggregated according to NUTS2 regions) are presented. However, adopting RISICO FDI World, such space-time aggregation is always available for specific needs.

USE OF RISICO WORLD MODEL FOR FORECASTING

<u>Check of critical moisture content to spot high probability of fire ignition.</u>

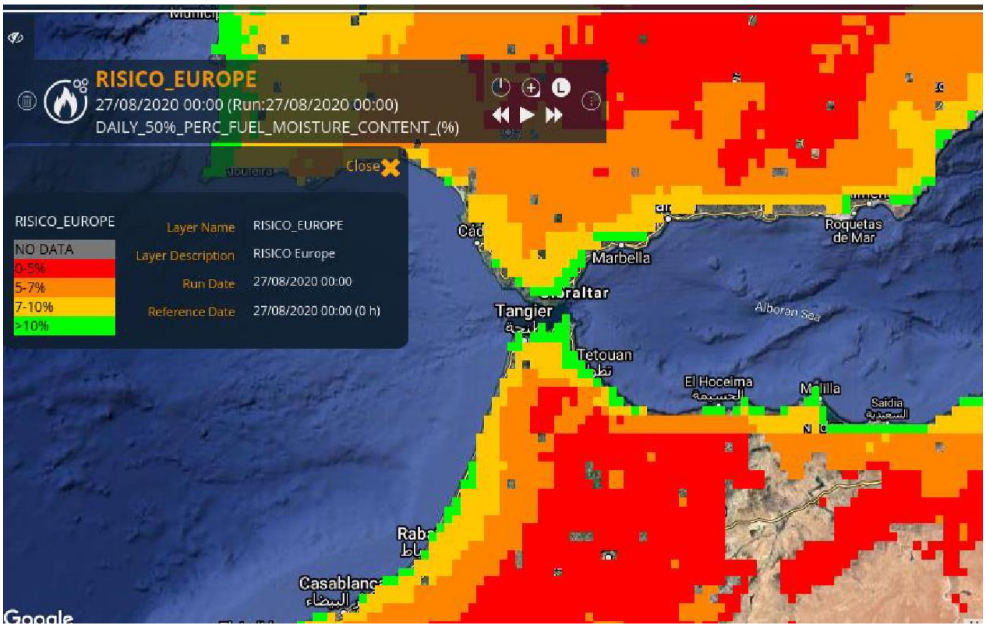
To see if a zone is characterized by persistent dry conditions, which may render it prone to wildfires, RISICO WORLD can provide temporal aggregates (daily information that gives out statistics of the Moisture trend) for the FFMC (Fine Fuel Moisture Content).

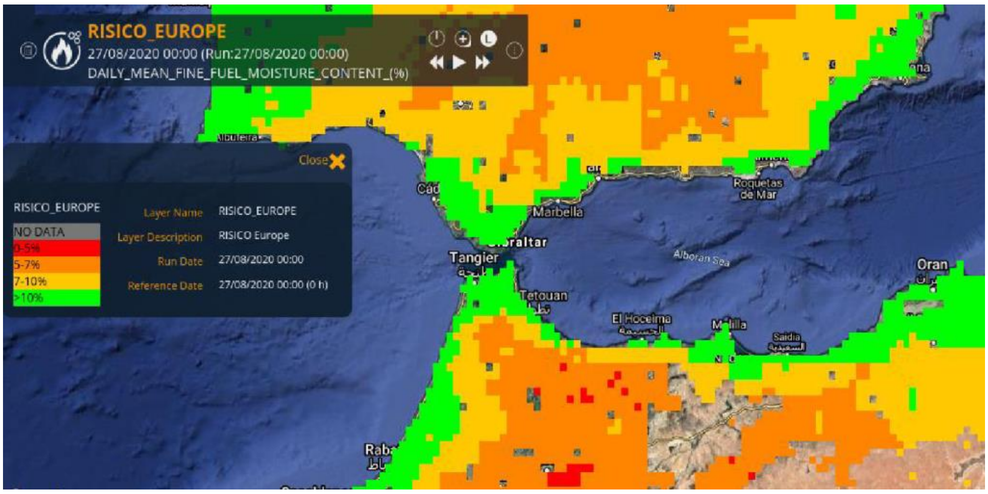


Each time you cast a layer, please make sure you are visualizing the right output time. In the PROPERTIES window, you can select the run date (that is, the date of the input files that generated the model) and the output time. The number of hours at the end of the string corresponds to the number of forecast hours (that is, the number of hours that span from the input data of the model to the desired output time). A positive number stands for a forecast, while a negative number stands for a reanalysis (we use data that we know in order to analyze past events).

<u>Daily statistics for FFMC: percentiles and mean - Aggregated analysis (50% percentile and mean)</u>

In this analysis, all the hourly information of RISICO outputs is considered as a whole sample (on a daily fashion) for each pixel. The results are ordered and only the 50% percentile of the highest values is considered. Red and orange areas are surely worth of further analysis.



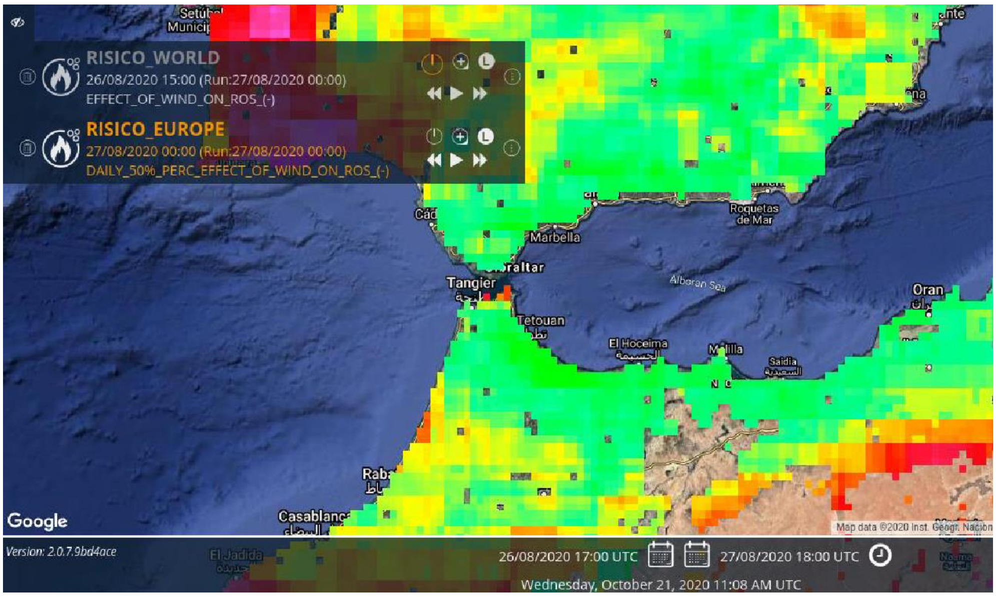


The mean can also help obtaining info on the overall temporal trend of the analyzed area: this aggregator uses every daily information and can shed light on the low fuel moisture level persistence.

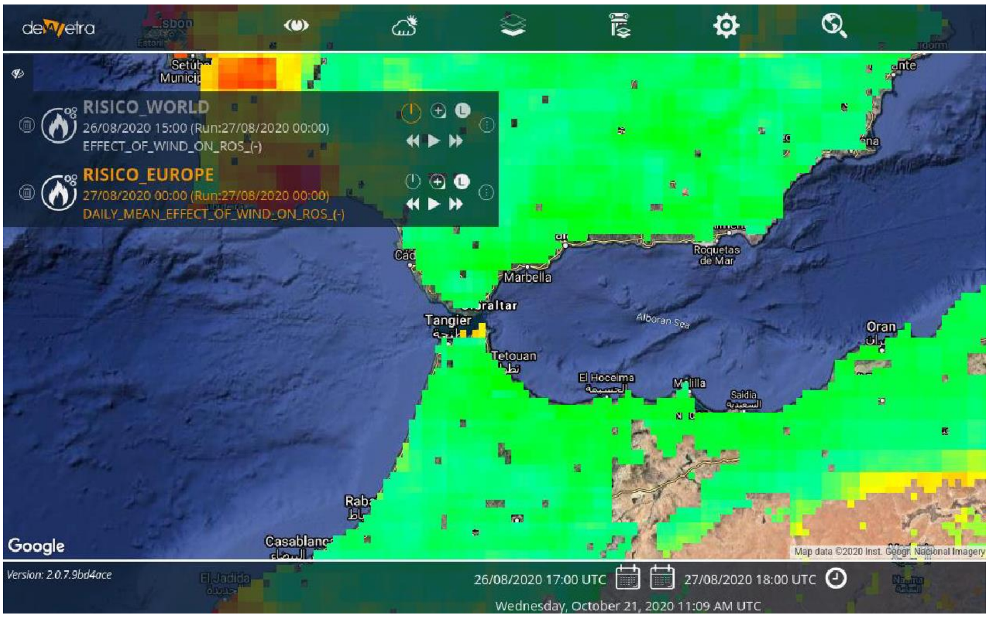
Wind conditions check: daily statistics for wind effect on RoS: percentiles and mean

If some area has a yellow-orange classification for what concerns FFMC levels, a further analysis considering the effect of wind is mandatory. More specifically, “Wind Effect on RoS” is a quantity which measures the wind impact on the computation of the Rate of Spread (RoS) (it is reminded that predictions and statistics over Rate of Spread are of course available as separate layers). Of course, also Wind Effect on RoS layer has at its disposal daily statistics in order to see if the wind effect is persistent on the whole day. In a similar fashion to what has been seen for FFMC, the 50% (highest) percentile and the temporal average (mean) are available.

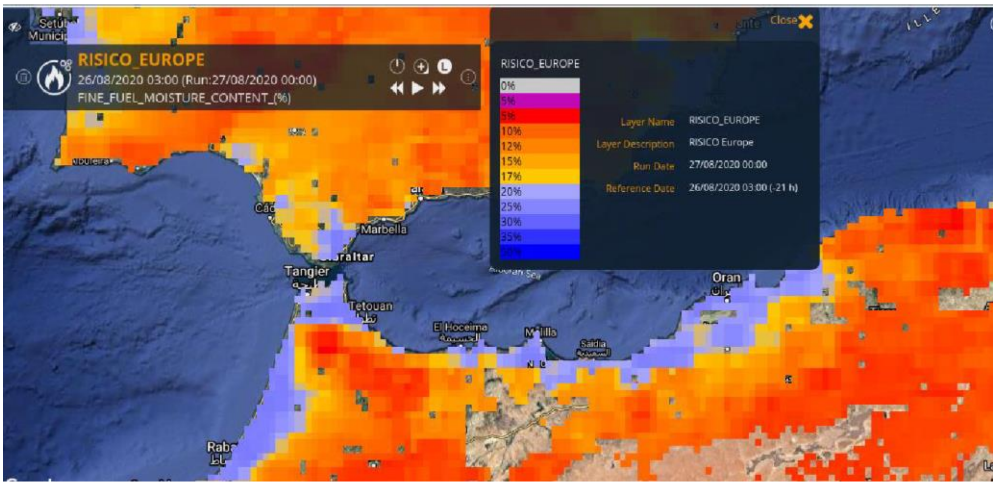
Analysis of 50% percentile of wind effect on RoS



Analysis of mean of wind effect on RoS



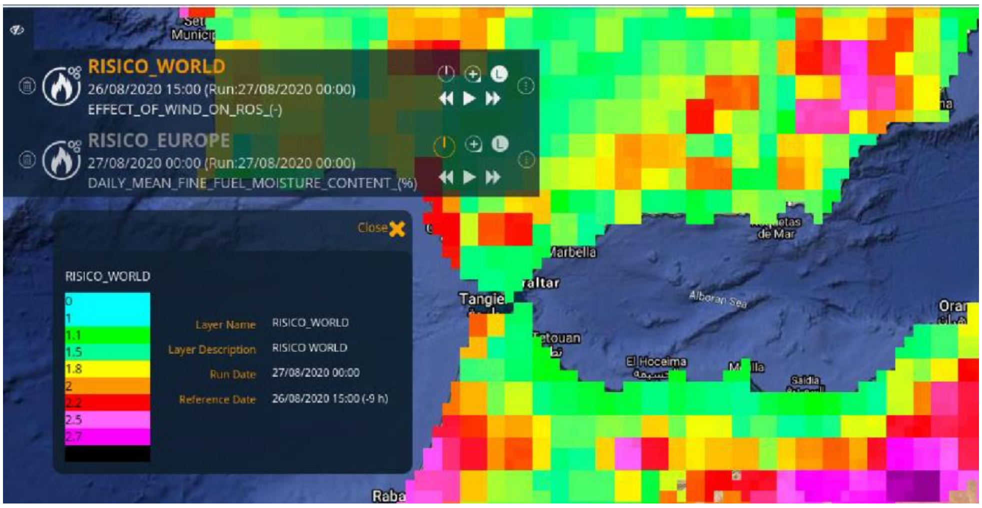
Finer analysis: three – hourly RISICO WORLD data



For further analysis, the temporal trend (with three hourly updates) of the RISICO WORLD variables is available.

The image below is an output of the RISICO FFMC for the Tangier area, Morocco. Zones characterized by moisture levels below 10% are experiencing critical conditions and therefore further analyses (such as vegetation cover) are mandatory.

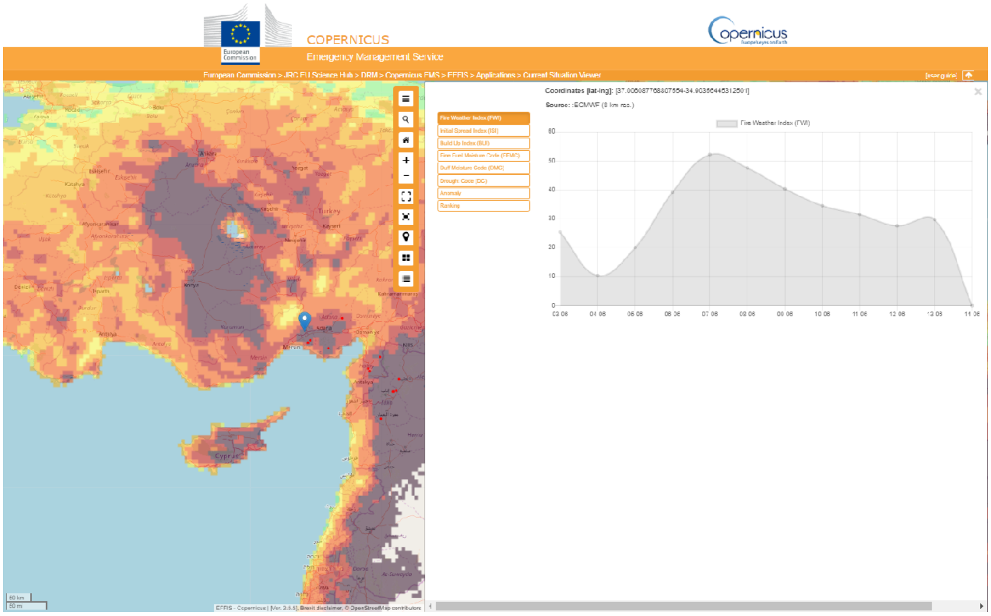
By looking at RISICO WORLD model, we have the three-hourly "Wind Effect on RoS" in order to have more insights on the temporal variability of the wind and its impacts on the Rate of Spread of an ignited fire.



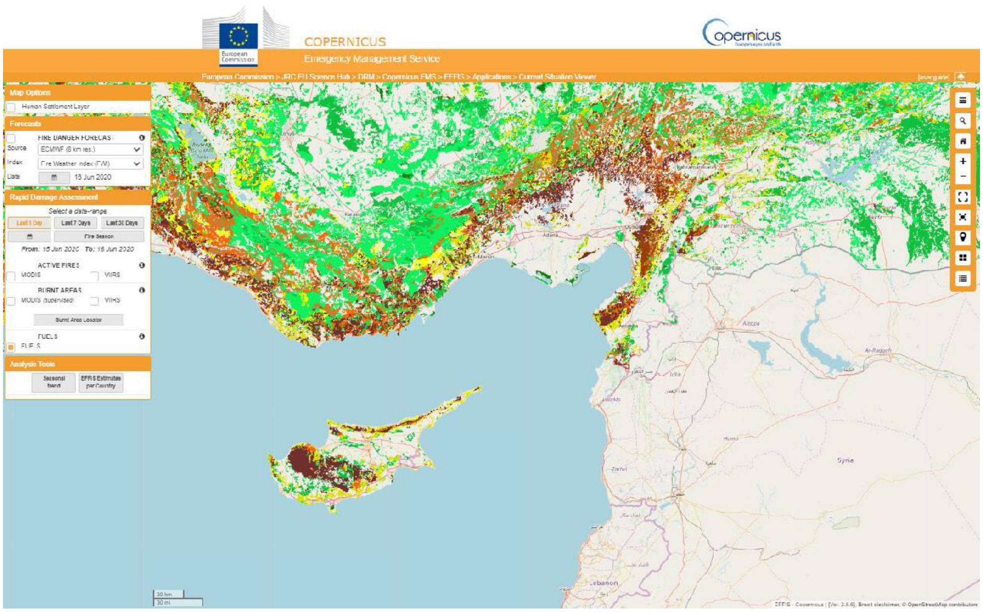
MODELS AVAILABLE ON EFFIS PLATFORM

For the areas selected in the previous steps, a deeper analysis on https://effis.jrc.ec.europa.eu/static/effis_current_situation/public/ can be carried out.

- Source: ECMWF [8 km]
    - Fire Weather Index and other sub-indices
- Source: ECMWF Probabilistic
    - Shift of tails (FWI, FFMC)
    - Extreme Forecast Index (FWI, FFMC)

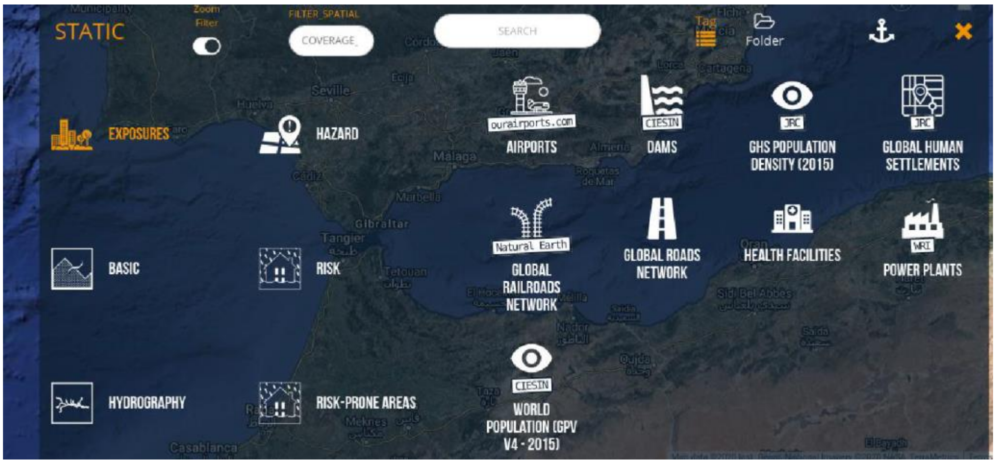


1) Wildfire hazard is only meaningful if there is vegetal fuel on the considered area. It is thus mandatory an analysis of fuel distribution over the area using https://effis.jrc.ec.europa.eu/static/effis_current_situation/public/index.html.



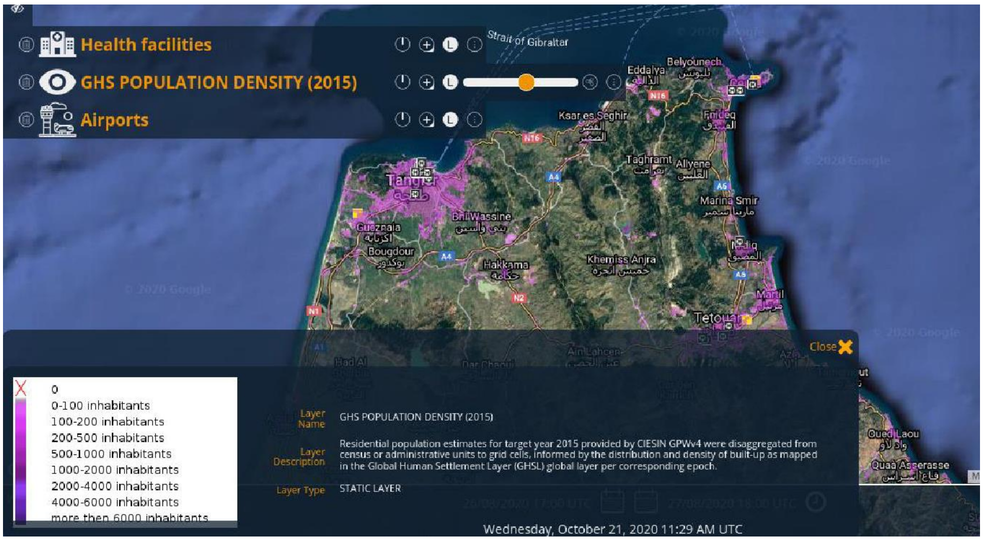
PHASE 3: ANALYSIS OF myDEWETRA.world STATIC LAYERS

For the points that have been flagged as "hazardous" due to FFMC and Wind conditions, a deeper analysis is advised. This analysis shall focus on the impacts of the possible wildfire ignition in the selected area.



By clicking on the "Static Layers" button, the user will have access to several layer categories.

For instance, the "Exposures" category allows the user to select different exposed infrastructures and exposed settlements.

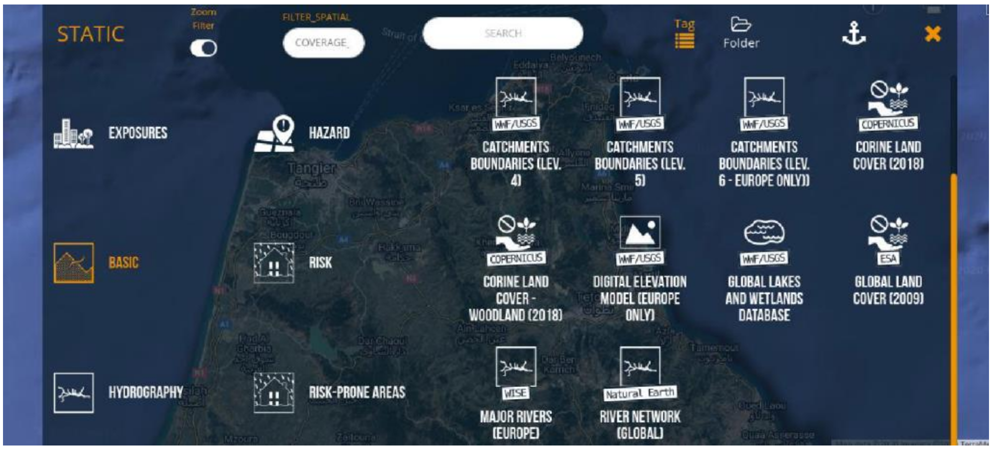


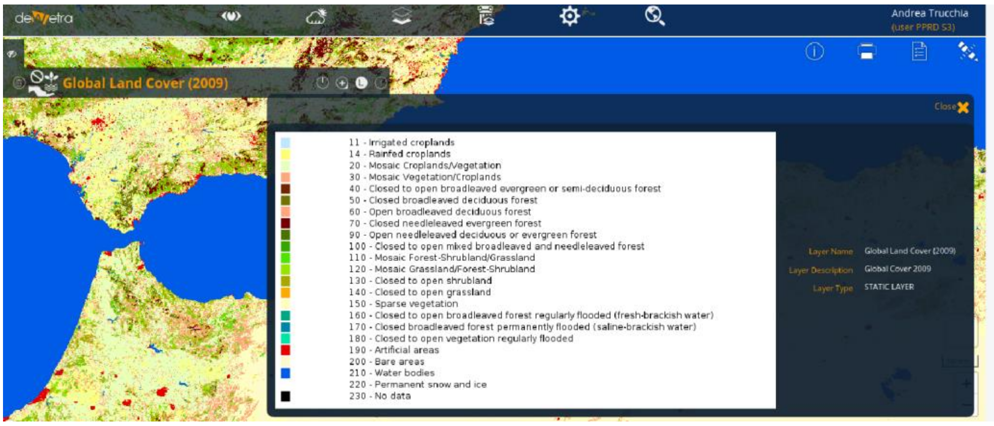
In the Figure above, the superimposition of three different static layers: GHS Population Density (in purple), Airports (yellow squares), Health Facilities (white "H" symbols).

By clicking on the "BASIC" static layer category, we can have access to Global Land Cover (2009), CORINE LAND COVER (2018) and CORINE LAND COVER – WOODLAND (2018).

The three of them come with a legend that explains the color pattern of the land use distribution.

For wildland exposed areas, the CORINE LAND COVER - WOODLAND focuses on the distribution of the different vegetation cover categories.





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