Ref. Ares(2025)11636679 - 31/12/2025

Extreme Wildfire Events Data Hub for Improved Decision Making

Union Civil Protection Mechanism (UCPM) call KNOWLEDGE FOR ACTION IN PREVENTION AND PREPAREDNESS, UCPM-2023-KAPP-PREP, Project number: 101140363

Deliverable title	D2.2. Guidelines and recommendations to strategically plan for extreme wildfire events
Contributing WP	WP2 – Knowledge Exchange
Dissemination level	PU
Contractual delivery date	31-12-2025
Actual delivery date	30-12-2025
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Document history			
Version	Date	Modifications	Source
D_v.1	25/11/2025	First Draft	NIPV
R_v.1	15/12/2025	Review	CFRS, PCF, HFS, WU
F	29/12/2025	Final Version	NIPV

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List of Acronyms

ABL	Atmospheric Boundary Layer
CLASS	Chemistry-Land-Atmosphere-Soil-Slab
EWE	Extreme Wildfire Event
EWED	Extreme Wildfire Events Data Hub for Improved Decision Making
LCL	Lifting Condensation Level
NDVI	Normalized Difference Vegetation Index
ROS	Rate Of Spread
WDP	Wildfire Data Portal
WUI	Wildland-Urban-Interface

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Executive Summary

This report provides guidelines and recommendations to organisations that address the challenges of Extreme Wildfire Events (EWEs). This is done through sharing important knowledge, as well as relevant processes and operational tools. The report emphasises the importance of analysing historical wildfires, managing uncertainty during EWEs, collecting data, making use of tools such as the CLASS model and the Wildfire Data Portal and knowledge sharing through international training events.

In summary, the report includes the following key recommendations:

1. **Analysis of historical wildfires:**
   Developing geodatabases of historical wildfire perimeters, identifying fire types and analysing spread patterns to help decision-making during future wildfire events.

2. **Uncertainty management:**
   Utilising the uncertainty matrix to assess known and unknown factors in fire scenarios and emergency response systems, focusing on safety and operational effectiveness.

3. **Specialised data collection teams:**
   Establishing dedicated teams to collect real-time atmospheric, plume and fire behaviour data during EWEs, enhancing situational awareness and reducing uncertainty.

4. **Modelling tools:**
   Applying the CLASS model for rapid assessment of environmental conditions in which a wildfire plume can develop, using real-world observations to improve accuracy.

5. **Wildfire Data Portal (WDP):**
   Utilising open-access wildfire case data as well as accessing Knowledge Clips to enhance the understanding of atmospheric conditions and pyroconvective plumes.

6. **International training and knowledge exchange:**
   Promoting collaboration between fire practitioners and scientists through training events to help create a shared understanding of EWEs through an interoperable language.

1. Introduction

1.1. General overview

In recent years, an increasing number of large wildfires that behave differently to what was expected have been observed. Examples of such fires (Extreme Wildfire Events – EWEs) are, among others, Fort McMurray (Canada), Pedrógão Grande (Portugal) or various fires in Greece (e.g. during the 2021, 2023 and 2024 (see Chapter 1.5) fire seasons). These types of wildfires cannot be tackled using traditional knowledge based on fires dominated by wind and topography and fuel, but rather by integrating these interactions into the analysis and operational planning. Decision-making must integrate the associated uncertainty that comes with these extreme wildfires and establish strategies and tactics that maximise cost-benefit, setting out resolution scenarios in line with the complexity of the extreme event. This represents a paradigm shift from reactive to proactive strategies.

In order to achieve this paradigm shift, more data from such fires is needed, focusing not only on fire behaviour parameters, but also on atmospheric parameters both at the surface and of the vertical structure of the atmosphere. However, it is important to then also be able to process and understand such data in order to make it efficient for decision-making. Hence, focussing on gathering data as well as increasing our understanding of EWEs has been one of EWED's focus points, resulting in various outcomes such as reports that are publicly available to read on the webpage of EWED.

1.2. Objective of the guidelines

This deliverable serves to inform fire practitioners from fire services or other regional, national or European-level institutions of important aspects that are, based on experiences from EWED, deemed important or essential in order to better prepare for Extreme Wildfire Events. Examples of such aspects are knowledge, processes or specific (operational) tools. Hence, this report shares guidelines and recommendations for these practitioners and/or institutions to use as a basis for better preparing for EWEs.

1.3. Reading guide

This report is targeted at fire practitioners or relevant organisations (e.g. fire services), providing basic recommendations and guidelines to better prepare and respond to EWEs. To this end, the following sections detail processes that individuals and organisations can incorporate to improve their capabilities and skills in the face of such events.

An important aspect of this is the collaboration between fire practitioners and scientists, as has been done throughout the process of the EWED project. Through clearly identifying the needs and knowledge gaps by fire practitioners, scientists can tailor their work such to best support these needs. Simultaneously, scientists can collaborate with fire practitioners to increase the understanding of relevant (atmospheric) processes that are not yet fully understood, using data that is gathered by practitioners.

It is important to note that these guidelines and recommendations mainly describe what knowledge and capabilities are important to have or knowledge that should be acquired. They are intended as basic guidelines rather than exhaustive implementation instructions, as specific approaches may vary across institutions depending on scale and governance structures. For those seeking more detailed and operational guidance, the references cited throughout this document include comprehensive materials and specialized protocols that can serve as valuable resources to complement and expand upon these recommendations.

1.4. Baseline knowledge needed to use the EWED content

To effectively use EWED resources, organisations and individuals need a solid foundation in fire analysis and assessment. This knowledge transforms key data into actionable insights for strategic, tactical, and operational decision-making. The following points outline the suggested path for organisations and personnel to evolve their capabilities, enabling them to transition from reactive suppression to proactive, scenario-based management.

For an **organisation** to successfully integrate EWED content, it is recommended that fire analysis is not treated as a minor task, but as a core strategic capability.

- A fundamental first step is a shared understanding of the EWE context. This involves recognising how shifting fire regimes have led to events that frequently exceed traditional suppression limits [5]. Understanding that we are facing a new generation of wildfires that can bypass traditional suppression capacity [9] is the first step towards integrating EWED tools effectively.

- Fire analysis capabilities should be integrated into the decision-making process at different levels. Each organisation should adapt its command structure to ensure that fire analysis directly inform both strategic planning and tactical execution.

- The creation of specialised units is a highly effective way to provide certainty during wildfire emergencies. These units act as organisational memory, combining lessons from past fires with new knowledge and translating technical data into clear guidance for all staff.

- By understanding the interaction between the fire and the atmosphere, fire agencies can take steps to move from a reactive strategy to one based on anticipation, identifying when and where a fire might transition into an EWE and define/adjust strategies proactively.

For **teams and individuals** involved in the analytical process, a progression of skills is recommended to handle the technical complexity of actual fire regimes:

- Meteorology, topography, and fuels are the pillars of fire behaviour. This includes understanding their interaction and evolution throughout the fire season, and their direct operational impact [3].

- Clear and consistent operational terminology is critical for effective communication. During emergencies, ambiguity can lead to delays or unsafe decisions. A shared operational language ensures that analytical outputs are understood and acted upon quickly by all operational levels.

- EWEs involve strong fire–atmosphere coupling. Analysts should learn to identify pyroconvection prototypes and understand how a plume interacts with the atmospheric boundary layer. This allows anticipation of phenomena such as sudden changes in fire behaviour, which standard fire behaviour models frequently fail to predict [2].

- Analysts must combine diverse sources (environmental observations, real-time fire behaviour, and local characteristics) while filtering out external noise [6]. This skill involves translating complex data into clear operational guidance, reducing uncertainty and aligning tactical objectives with the suppression capacity available (see Chapter **Error! No s'ha trobat l'origen de la referència. Error! No s'ha trobat l'origen de la referència.**). By anticipating transitions to extreme behaviour and communicating insights effectively, analysts enhance both firefighter safety and the overall effectiveness of the response.

Ultimately, establishing this baseline knowledge is critical because EWED resources are not automated solutions, but advanced decision-support tools. Ensuring that organisations and individuals possess these core competencies is what allows the content to be applied effectively, transforming complex atmospheric data into the strategic vision necessary to manage the inherent risks of extreme wildfire events.

1.5. Why we focus on Extreme Wildfire Events - The 2024 Varnavas (Greece) fire as an example

The Varnavas wildfire of August 2024 in Greece is a clear example of how extreme fire behaviour can result in challenges in how the resulting uncertainty affects the operational strategy. With an ignition at midday in the Attica region, which was experiencing a prolonged period of drought and high temperatures, allowed the fire to quickly become one of the most challenging fires of the Greece's fire season. Although the day's conditions were already classified as 'Fire Risk 5', the maximum Fire Risk Level available in Greece, the fire behaviour that followed with the Varnavas fire went far beyond what the fire service expected based on available forecasts.

1.5.1. Expected fire behaviour

On the day of the ignition, weather forecasts indicated temperatures of around 32 degrees Celsius, low humidity and strong northerly winds. These conditions supported the occurrence of fast-moving fires, aligned with the wind direction. Moderate to high spread rates were forecasted, but no significant vertical plume development was forecasted along this. Atmospheric data from the wider region also implied a stable upper atmosphere.

Operationally, the fire service planned for a rapid initial attack, supported by aircraft, and the possibility of gaining control of a fire during the night, when the winds normally ease. The fireline intensity was anticipated to remain within a range that would allow direct suppression activities on the flanks and tail of a fire.

1.5.2. Observed fire behaviour

The Varnavas wildfire, contrary to the forecasted fire behaviour, rapidly transitioned from a wind-driven fire to a plume-dominated event. Within a short time after ignition, observers saw a developing overshooting pyrocumulus cloud. As the plume gained strength, the fire accelerated dramatically, at times reaching a Rate of Spread (ROS) of 4.5 km/h when the forming pyrocumulus cloud altered local atmospheric conditions. This also resulted in larger burn rates, up to 2750 ha/h, than was forecasted based on the regular (surface) weather conditions.

The fire behaviour became even more unusual during the night. As, contrary to the calming winds that were forecasted for the night, the winds remained strong and thus the fire also maintained a high intensity and spread rate throughout the night, taking away the forecasted window of opportunity to effectively work on the fire.

The fire burned 10.414 hectares in total, impacting more than 30 communities.

Figure 1 The plume of the 2024 Varnavas wildfire. Source: Hellenic Fire Service.

1.5.3. Operational consequences and challenges

The unexpected fire behaviour that occurred at the 2024 Varnavas fire had an immediate effect on the fire suppression strategy. After ignition, the fire quickly threatened the wildland-urban interface, forcing a strategy from direct attack to community protection. More than 30 settlements required evacuation or shielding efforts. Given the intensity at the head of the fire, placing fire crews directly in front of it would have been too dangerous, especially with low visibility conditions and erratic winds and fire conditions due to the plume-driven fire behaviour.

Aerial operations, although activated quickly, were soon hampered by the growing plume and turbulence near the fire. Aircraft struggled with poor visibility and unstable (turbulent) air, reducing their ability to slow the fire's advance during its most extreme phases.

Figure 1. A view on the convective plume of the 2024 Varnavas wildfire as seen from one of the aerial resources. Source: Hellenic Fire Service

1.5.4. Wider implications

The Varnavas wildfire in Greece highlighted the limits of predicting fire behaviour during plume-dominated events. The effect of the plume-dominated fire behaviour of the wildfire was not expected and thus resulted in an unforecasted increase in wind speed and thus an acceleration of the fire front.

For operations, the Varnavas fire underscored the need for faster, real-time atmospheric information, including the use of radiosondes close to active fires, and for prediction systems that integrate wildfire plume dynamics. It also reinforced the growing challenge of protecting densely populated wildland-urban interface (WUI) areas during fires that exhibit extreme fire behaviour. This extreme and erratic fire behaviour also illustrated how uncertainty in the fire's scenario can impact strategy, tactics and thus also firefighter safety.

As such events become more common, preparing for this type of fire plume-dominated fire behaviour – rather than relying solely on the classic understanding of fire behaviour based on surface weather conditions and topography– will be essential for effective and safe wildfire management in the future.

To conclude, there is a strong need for being able to strategically plan for EWEs. Although the scenario of a wildfire could still be uncertain due to the extreme fire behaviour, managing the emergency response while taking into account this uncertainty is essential.

2. Guidelines and recommendations

2.1. Analysis of historical wildfires

The period shortly after the ignition of a wildfire is one with many unknowns. Where exactly is the ignition point? What is the current fire behaviour? Where is the fire spreading towards? Are there critical points or infrastructures nearby? Is the area around the wildfire easily accessible? Until the first resources arrive in the area, there is a high level of uncertainty. However, with the data that is being collected since the start of the wildfire, a fire service can decrease the uncertainty [8]. As an essential part of this, the fire's current conditions and location is compared to the conditions and locations of historical fires. Once similarities are found, this means that fire analysts or other operational teams can use the data from these historical fires, for example about the fire behaviour and spread conditions (Rate Of Spread (ROS), spread direction, et cetera), to forecast the fire behaviour of the current fire. Hence, it is important to have data and an understanding (also see Chapter 1.4) of a country's or region's historical fires, not only to learn lessons from them afterwards, but also to make use of them operationally during current and future wildfire episodes. In the next sub-chapters, this is further elaborated.

The importance of analysing and being aware of the historical wildfires of a region, can also be shown through an example from The Netherlands. On the 2nd of July 2010, at approximately 14:00 CET, a wildfire started in the Strabrechtse Heide nature area. Based on the available information in The Netherlands to date, this has been the only wildfire in recent years in the country that exhibited active crowning in its fire behaviour. Although reports on the fire mention strong winds and changing wind directions, also through reports from firefighters in the field, there was no mention of the synoptical situation, vertical state of the atmosphere or a link made to a fire type [10]. However, after further post-fire analyses, using newly provided footage of the fire and the plume, it became apparent that the fire at the Strabrechtse Heide in 2010 was a convective fire, as a clear pyrocumulus cloud was observed. This is also the likely cause of the observed strong winds and changes in wind direction by the firefighters near the fire. Through this information, linked to the synoptical situation –A moderate south wind with dry and unstable conditions with drought conditions within the 5% driest years observed in The Netherlands– this fire can be used to anticipate future convective fire scenarios in case similar conditions are forecasted when additionally using the newly gained knowledge about EWEs. Additionally, analysing such cases cannot only help learn from one's own experiences, but also experiences from neighbouring countries.

Figure 2 Photos of the plume of the Strabrechtse Heide (2010) wildfire in The Netherlands. Source: Hans Stans.

2.1.1. The fire types concept

For analysing historical wildfires, it is recommended to make use of the 'Fire Types' concept [9]. This concept is a methodological framework that classifies wildfires in a given region according to their typical spread patterns, mainly based the interaction between the weather conditions and the landscape/topography. The Fire Types concept can support wildfire operations by allowing the analysis of a current fire using the knowledge of how historical fires spread under similar weather conditions and in the same landscape. However, the concept can for example also support forest planning actions through understanding where preventive measures such as fuel treatment are most important to take by being able to identify critical areas or opportunities based on historical fires.

There are four main spread patterns that can be identified and on which the fire types are based:

- Topographic fires
- Wind-driven fires
- Convection-dominated fires
- Storm-dominated fires

These main spread patterns have been sub-divided into several fire types through determining the dominant factor driving the fire spread. Finally, per fire type, a description of typical spread characteristics and relevant opportunities for fighting the fire are given. The table below provides a full description of these aspects per fire type.

Table 1 Fire Types with a description of the spread scheme and strategies or opportunities for control. Table is based on [9] and adapted for the convection-dominated wildfires from [2].

Spread pattern	Dominant factor	Fire type	Spread scheme
Topographic	Topographic slope winds	Standard topographic fire	Follows the slopes with the steepest gradient and highest insolation at daytime. Forms of the perimeter are defined by the slopes and hydrographic basins. The critical points are ravines, intersections of ravines, and the position of the back and flanks of the fire at a point with the potential for new runs.
	Sea breeze	Coastal topographic fire	Follows the steepest slope and the defined and predictable turn of the sea breeze. Opening of the flanks or tail is dominated by sea breeze.
	Topographic winds of the main valleys	Topographic fire in main valleys and canyons	The main direction of the perimeter is in the direction of the main valley. A suction of the fire toward the main valley is generated by the venturi effect. There is a change of the ascending daytime suction to a descending suction at night.
Wind-driven	In level terrain	Wind-driven fire in level terrain	Follows the wind direction and opens in an angle of 30 to 60 degrees, depending on the strength of the wind.
	In mountainous terrain	Wind-driven fire in mountainous terrain	In mountain ranges aligned with the wind direction, it follows the ridge lines. In mountain ranges perpendicular to the wind direction, counterwinds (rotor winds) occur that facilitate the ascending spread because of turbulences on the slopes of the opposite side that is not directly exposed to the wind. Opportunities: at the end of the water divide, or when the divide

			changes the direction, at bifurcations, or when the counterwinds occur.
	In subsidence zones with descending winds. With general winds along the surface at night and rising up during daytime	Wind-driven fire with subsidence	Phenomenon of coastal ranges in front of a large plateau that falls abruptly (central-eastern coast of the Iberian peninsula, coast of California, Greek Peloponnese), when the diurnal topographic winds are able to compensate the northerly winds at altitude. When this happens, the topographic winds are descending at night while the northerly winds descend along the surface and are reinforced by topographic winds. Therefore, the fire behaves like a topographic fire during the day and like a wind-driven fire during the night. This dynamic implies that the back of the day-time fire is transformed into its head at night and vice versa. This imposes difficulties to the incident management.
Convection-dominated	Without significant winds	Standard convection-dominated fire	Follows the macro-topography and the (limited) wind. Opportunities: confining the head or measures to reduce spotting activity.
	With significant wind, often accompanied with hot air masses	Convection-dominated fire with wind	Convective fire behaviour plus the wind affecting the fire spread. The wind increases spotting distance, creating new ignition points outside the influence zone of the convective column and accelerating the general spread of the fire. The column and the spots follow the wind direction. However, the fire ends up burning large topographical basins
	With the production of an overshooting pyrocumulus	Dry convection with overshooting pyrocumulus	Convective fire behaviour with often short-lived pyroCu clouds that form in a somewhat stable ABL, with a condensation level (LCL) above the ABL.
	With the production of a resilient pyrocumulus	Moist convection with resilient pyrocumulus	Convective fire behaviour with a persistent pyroCu cloud in an unstable ABL with a LCL below the ABL height. The vertical growth of the cloud is limited by shear or stability in the free troposphere.
	With the production of a deep pyrocumulus or pyrocumulonimbus cloud	Moist convection with a deep pyrocumulus or pyrocumulonimbus cloud	Convective fire behaviour with a persistent deep pyroCu or pyroCb cloud, using free convection in an unstable free troposphere. The convective column can collapse once the fire loses intensity, resulting in possible strong (dry) downbursts, massive spotting, extreme increases in rate of spread and extension of the fire in all directions.
Storm-dominated	With a storm close to the fire	Nearby (thunder)storm	When thunderstorms form or move nearby an active wildfire, the fire can get affected by a suction of air (inflow) by the storm. The storm can also push cold and often moist air away from itself (outflow). The fire's spread is affected by these changing winds. Erratic and generally uncertain fire behaviour is possible. The change from inflow to outflow winds could mean a significant change in spread direction
	A storm with dry lightning	Dry thunderstorm	Next to inflow and outflow winds, dry thunderstorms can create new (multiple) ignitions of new fires, resulting in a scenario with simultaneous wildfires, generally in the same region.

2.1.2. The information needed to analyse historical wildfires

2.1.2.1. The conditions under which the fire occurs

When looking at historical wildfires, one should first of all have information about the conditions under which the fire occurred. Table 2 shows examples of this type of information.

Table 2 Examples of relevant information about the conditions a fire has occurred in, based on [12].

Weather conditions	Fuel conditions	Topography
Synoptical weather: • general pressure distribution, • frontal analysis • 500 hPa (air masses) maps and 850hpa temperature Surface weather conditions: • Temperature • Relative humidity and dew point • Wind direction & speed • Past precipitation • Cloudiness Atmospheric vertical conditions (temperature, humidity and wind): • Modelled vertical profiles • Observed vertical profiles (if available) • Visual indicators of ABL conditions, such as the presence of cumulus clouds	• Fuel model(s) • Fuel availability for dead and live fuels (observed, or based on visual indicators) • Estimated fuel conditions such as fuel load	• Altitudes (above sea level) • Slope angles • Slope aspect (orientation) • Slope roughness

It is important to note that the information above does not always have to be precisely and quantitatively defined. For example, for landscape-scale monitoring of fuel dryness, it is often preferred to be done through remote-sensing or visual indicators such as the Normalized Difference Vegetation Index (NDVI), instead of relying on dense field sampling, as pointwise field samples could be considered expensive and difficult to interpret when the measurements are performed in a heterogeneous landscape.

2.1.2.2. The exhibited fire behaviour

In order to be able to forecast the fire behaviour with (near-)future wildfires well enough, having access to data for historical wildfires is considered important [4]. These data should, if the information is available, at least consist of the following:

1. Information about the ignition
    - Approximate time of ignition
    - Ignition location
2. Fire behaviour & Dynamics
    - Fire perimeter evolution in Isochrones, preferably in hourly timesteps
    - Total area burned (final perimeter)
    - Total duration of the fire, separated in phases (active, stabilised, controlled & extinguished)

- Observed type of affected vegetation layer (ground, surface, crown or a mix of this)
- Rate of Spread (in m/h)
- Burn rate (ha/h)
- Fireline intensity:
  - Flame length (m)
  - Depth of the flaming front (m)
  - Width of the flaming front (m)
- If present, crown fire type (e.g. passive (torching) vs active crowning)
- Spotting distance, separating massive spotting distance and maximum spotting distance
- Fuel consumption:
  - Dead fuels – 1, 10, 100 and 1000h fuels
  - Live fuels

2.1.3. Link to the Fire Types concept as an operational tool

Once there is a list of historical wildfires from one's country or region, the fires can be linked to the Fire Types, such as the ones listed in Table 1. When analysing the weather forecast, it then becomes clear that possible wildfires could exhibit similar fire behaviour and spread patterns as historical wildfires that occurred under similar meteorological conditions and in similar topography as the forecasted conditions fit a certain fire type.

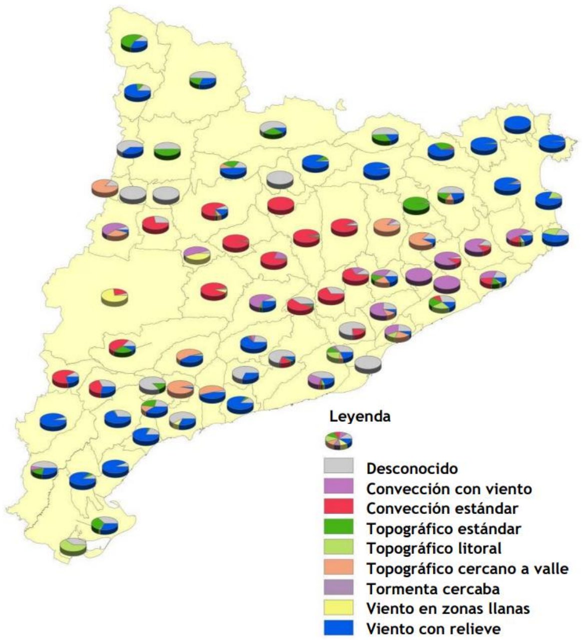

Figure 3 Overview of the distribution of different fire types over different regions for the autonomous region of Catalonia (Spain). Source: [7].

Comparing the forecasted conditions with the database of historical wildfires, linked to the fire types, also allows for analyses of, for example, areas with the highest risk of ignitions and problematic fire spread. This requires an analysis of the distribution of regions with homogeneous fire regimes based on the Fire Types concept as is shown in the example of Catalunya in Figure 3. Through this, a fire service could adapt its suppression and response plan, for example through prepositioning (aerial) resources to the risk areas or strengthening the initial attack after the first call for a wildfire through sending more resources in the first phase of the fire. It could also affect the initial tactics used by the first units that arrive on scene, for example by directly anchoring the wildfire and not attacking the head of the fire as they already know the head of the fire is likely beyond suppression capacity, ensuring firefighter safety.

2.1.4. Checklist for analyses of historical wildfires

Below, a brief checklist is added that, based on the previously described relevant data and information, can serve as a simple checklist to help in implementing the Fire Types characterisation methodology.

1. **Create a geodatabase of historical fire perimeters:**
    a. Reconstruct perimeters of historical fires, e.g. through satellite data
    b. Backdate and characterise the found perimeters
    c. Collect and synthesise initially available information of the fires
2. **Identify the meteorological situation at a synoptical level for each backdated wildfire**
3. **Reconstruct the fire spread patterns:**
    a. Examine the different spread schemes linked to meteorological situations:
        i. Catalogue perimeters according to their spread patterns
        ii. Determine the different Fire Types linked to the spread patterns and synoptical weather patterns
        iii. Classify all wildfires according to the available Fire Types.
4. **Locate and characterise zones with homogeneous fire regimes through identifying recurring Fire Types.**

2.2. Uncertainty management during EWEs

Extreme Wildfire Events are characterised by rapid changes in fire behaviour and, as a result of this, sometimes also limited control options [5]. Hence, effective management depends on recognising what is known and unknown about two main components that form the foundation of the uncertainty matrix [8]:

- What is known and unknown with regards to the emergency response (what is the capacity you have available and what you can or cannot do with it)
- What is known and unknown from the fire scenario (do you know what the fire wants to do and can do)

An overview of the uncertainty matrix is provided below:

Table 3 The uncertainty matrix, taken from [8].

		Fire scenario	
		Known	Unknown
Emergency response system	Known	Known scenario. Safety protocols and predictability work	Uncertain scenario but operational response is known and predictable. Black swans would not be detected. The scenario must be changed
	Unknown	Known scenario but uncertain operational response. Tactics should be modified to develop certain scenarios	Uncertain situation. The evolution of the scenario is not known, nor is the operational response. Situation must be reconsidered.

At any stage of an EWE, decision-makers should assess how well the fire behaviour and environmental conditions, as well as the capabilities and limitations of the emergency response system, are understood. By doing so, and through using the uncertainty matrix, for main situations can be identified:

1. Both the fire scenario and the response system are known: Known-Known
2. The response system is known, but the fire scenario is unknown: Known-Unknown
3. The fire scenario is known, but the response system is unknown: Unknown-Known
4. Both the fire scenario and the response system are unknown: Unknown-Unknown

Applying standard suppression activities in a situation where there is an unknow, means uncertainty and thus operational risks, both in terms of effectiveness and operational safety. Hence, decision-makers should always aim to control the factors such that they end up in a Known-Known situation.

During EWEs, especially the fire scenario can quickly be unknown, as the change in fire behaviour is extremely uncertain. When trying to fight that scenario with the available capacity, one can easily end up in an Unkown-Unkown situation. Under those circumstances, a Known-Known situation can be achieved through:

- Accepting that direct control of the fire may not be possible at that time, affecting the resolution of a wildfire event
- Prioritising firefighter and public safety above asset protection
- Ensuring plenty of time for evacuation if needed, especially because the fire may intensify and speed up during EWEs. If this cannot be guaranteed, confinement in safe buildings might be a better option in order to prevent civilians getting caught up by the fire during evacuation.

2.3. Data collection teams

It is recommended for countries or (autonomous) regions to have specialised data collection teams, especially during EWEs. Frontline firefighters must focus on safety, tactics and their direct suppression activities. This means that they rarely have the time or capacity to collect detailed atmospheric, plume and fire behaviour data. Hence, dedicated teams to do so is considered a recommended best practice, as they ensure that the data collection does not compromise suppression efforts. The data collection teams can also support the overall situational awareness through their observations and measurements whilst avoiding directly interfering with suppression operations [1]. These teams would also guarantee the data collection in a systematic way, whereas data collection through fire personnel already involved in suppression activities is more opportunistic.

EWEs involve complex fire-atmosphere interactions, requiring teams that are trained in radiosonde deployment, plume interpretation, fire behaviour observations and further basic atmospheric analyses. This expertise generally goes beyond the standard firefighting tasks. Specially trained data collection teams thus enables:

- The correct selection of launching position for radiosondes, whilst maintaining safety
- Understanding when and how to collect plume, meteorological and fire behaviour data
- Consistent documentation and formatting that is compatible with for example the Wildfire Data Portal (WDP).

By focusing explicitly on data collection and real-time analysis of this data, these specialised data collection teams can, for example, help identify approaching transitions to (more) extreme fire behaviour. Hence, these teams do not solely collect data that is important to analyse and upload after a fire, but can also offer early insights throughout the active phase of the fire that can support operational planning and decrease uncertainty of the fire scenario.

Below, some more aspects of the data collection teams are briefly further elaborated, for example data collection during EWEs. A more comprehensive overview of these aspects is available through [4].

2.3.1. General data collection

Data collection teams should focus on gathering information on the variables that best describe the evolving conditions of the atmosphere and a wildfire's plume, as well as fire behaviour and changes in fuels or the landscape. In general, they should gather as much information as possible. This data does not only help with situational awareness during the incident, but also allows post-analyses of wildfires. An overview of the information that should be gathered is provided in Table 2. The parameters in this table also correspond to the requirements for data gathered about the wildfire evolution as is described in [4].

2.3.2. Data collection during EWEs

During EWES, data collection through the radiosonde methodology is crucial. Radiosondes launched both inside the fire plume and in the environment near a wildfire allow comparison between the fire-modified and ambient atmosphere, providing information on the current fire conditions as well as the possible future conditions, for example when a radiosonde measurement shows that the fire's plume has the ability to keep growing vertically, reaching the condensation level or deepening the already present pyro-cloud. To successfully do this, based on [1] & [4], teams should:

- Launch radiosondes frequently, and from different positions of the fire (head, flanks or the back of the fire.
- Next to launching in-plume, also launching a radiosonde in the ambient atmosphere no more than 1 hour before or after the in-plume radiosonde.

- Record the exact GPS location of the launch site, time of launching, and position of the launch site relative to the fire (e.g. from the left flank).
- Maintain video and photo documentation of the launch, allowing the contextualisation of the data.

2.4. Modelling tools to forecast EWE occurrence

Wildfire operations benefit from tools that can combine observations with fast, physically based modelling. The Wildfire Data Portal can provide in this by linking wildfire observations to a dedicated modelling environment. One of the operational tools, available through the portal, is the CLASS (Chemistry-Land-Atmosphere-Soil-Slab) model. This model has been developed to simulate the atmospheric conditions, as well as what a wildfire plume would do under specific conditions. The information below is based on experiences through EWED and [13].

2.4.1. The use of the CLASS model

The CLASS model is a simplified atmospheric model that focuses on the daytime boundary layer, where most wildfire-atmosphere interactions are expected to occur in. It simulates how temperature, humidity, wind and atmospheric stability evolve during the day and how these factors interact with a wildfire plume. The model allows users to estimate plume height and depth under given weather and fire conditions. This is a tool aiming to support practitioners with fire analysis skills to assess the potential for convective fire behaviour.

The CLASS model can also be used for rapid testing of scenarios, for example through increasing the amount of energy released by a fire in order to test the effect of a larger wildfire or more intense fire behaviour on the plume dynamics. It is also possible to alter atmospheric conditions, for example through increasing the amount of moisture in the atmosphere, which could be done to simulate the possible effect of a sea breeze entering a wildfire and affecting the plume.

Unlike regular atmospheric models, which can take hours to run and require specialised computing resources that are expensive to run, CLASS performs calculations in seconds to minutes. This makes it suitable for operational use, particularly during rapidly evolving wildfire situations when timely information is essential.

2.4.2. Using real-world observations to improve assessments

An important strength of the CLASS model is its ability to make use of observational data. Radiosonde measurements taken in a wildfire plume or the ambient atmosphere, provide valuable information on the atmospheric structure. These observations can then be used to constrain or adjust CLASS simulations, ensuring that the model output reflects the actual conditions at the fire as realistically as possible. By running the model with these observations, practitioners can, for example, better understand how close the atmosphere or the wildfire plume is to thresholds associated with extreme fire behaviour. An example of this could be assessing how close the fire plume would be to condensation (formation of a pyrocumulus cloud), which is likely to significantly affect the fire behaviour. Figure 4 shows a graph from the CLASS model with two timeseries of the LCL (left) and the plume height (right) for different heat release values of the Martorell wildfire case. When comparing the model output with current actual wildfire plume conditions, such graphs can then be used to analyse whether a fire could be close to reaching condensation and consequently be changing in fire behaviour.

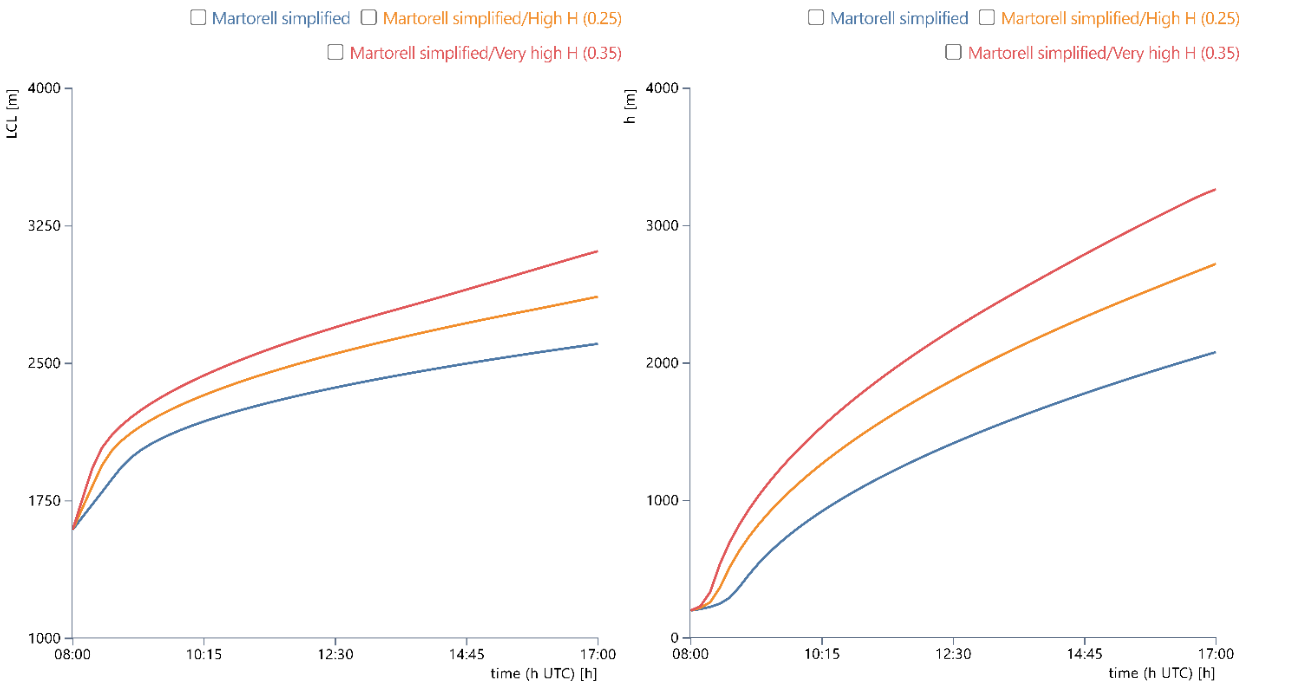

Figure 4 Example of CLASS output based on a simplified model run of the Martorell wildfire case as is available through the WDP. The graph on the left shows a timeseries of the LCL for three plume model runs and the graph on the right shows a timeseries of the plume height for the same three plume model runs.

2.4.3. CLASS model: rules of thumb for fire practitioners

In order to support the operational use of the CLASS model, fire important rules of thumbs for fire practitioners such as fire analysts are provided below.

1. **Use CLASS to rapidly adjust to changing conditions**
   Apply CLASS when rapid insight is needed to adjust to changing conditions and regular (and complete) atmospheric modelling tools are likely too slow
2. **Focus on plume behaviour, not detailed weather information**
   CLASS is designed to assess plume height, depth and fire-atmosphere interactions. The model is not built to directly also model fire spread patterns and horizontally changing weather conditions. The best use is for finding and analysing EWE thresholds such as how far the plume is from reaching condensation
3. **Watch for EWE thresholds**
   Wildfire plumes can be sensitive to relatively small changes in atmospheric stability, for example the change in temperature above the ABL. Also a change in fire intensity can have a relatively large impact on the plume dynamics. Hence, focus on using CLASS to analyse EWE thresholds such as how far the plume is from reaching condensation or how easy it is for a fire plume to keep deepening.
4. **Use real-world soundings when possible**
   Observed radiosonde profiles provide the most operationally accurate and thus relevant input. When available, use these observations to make the CLASS model as accurate as possible.
5. **Compare scenarios, not single outcomes**
   Relative changes between runs in CLASS can be more meaningful than one simulation and focussing on the exact numbers. Hence, a sensitivity analysis can be important. For example, think of changing the fire intensity in the model to take into account possible changes in fire behaviour.

When not to use CLASS:

Do not use CLASS for detailed local weather forecasts of fire spread modelling, as it is a tool that is created for a rapid interpretation and sensitivity analysis in the context of forecasting the environmental conditions in which a wildfire plume forms in can interact with. Numerical weather predictions and fire spread modelling involve more complex computations and generally serve different purposes.

2.5. Knowledge and data on the WDP

Another recommendation is to use the available knowledge and data that has been made available on the Wildfire Data Portal through the EWED project [11]. This can be divided in two main parts.

The first part is the Knowledge Clips that are freely available on the WDP. These videos, generally with a total duration of 10-15 minutes per video, briefly introduce important aspects with regards to EWEs. The first videos (1-3) introduce the physics and environment of pyroconvective plumes. The next videos (4-7) introduce the Skew-T diagrams which can be used to analyse the vertical atmospheric conditions, which could support in forecasting pyroconvection conditions. Finally, the last videos (8-10) focus on actual measurements with convective fires, while also introducing a new concept with conserved variables which can be used to analyse real pyroconvective events. The videos have the following structure and titles:

1. Why do plumes rise?
2. Atmospheric Boundary Layer
3. Lifting Condensation Level
4. How to read Skew-T diagrams?
5. The ABL and LCL in a Skew-T
6. Skew-T diagrams with wildfires
7. Online tools for Skew-T's
8. Pyroconvection prototypes
9. Conserved variables
10. Soundings in reality

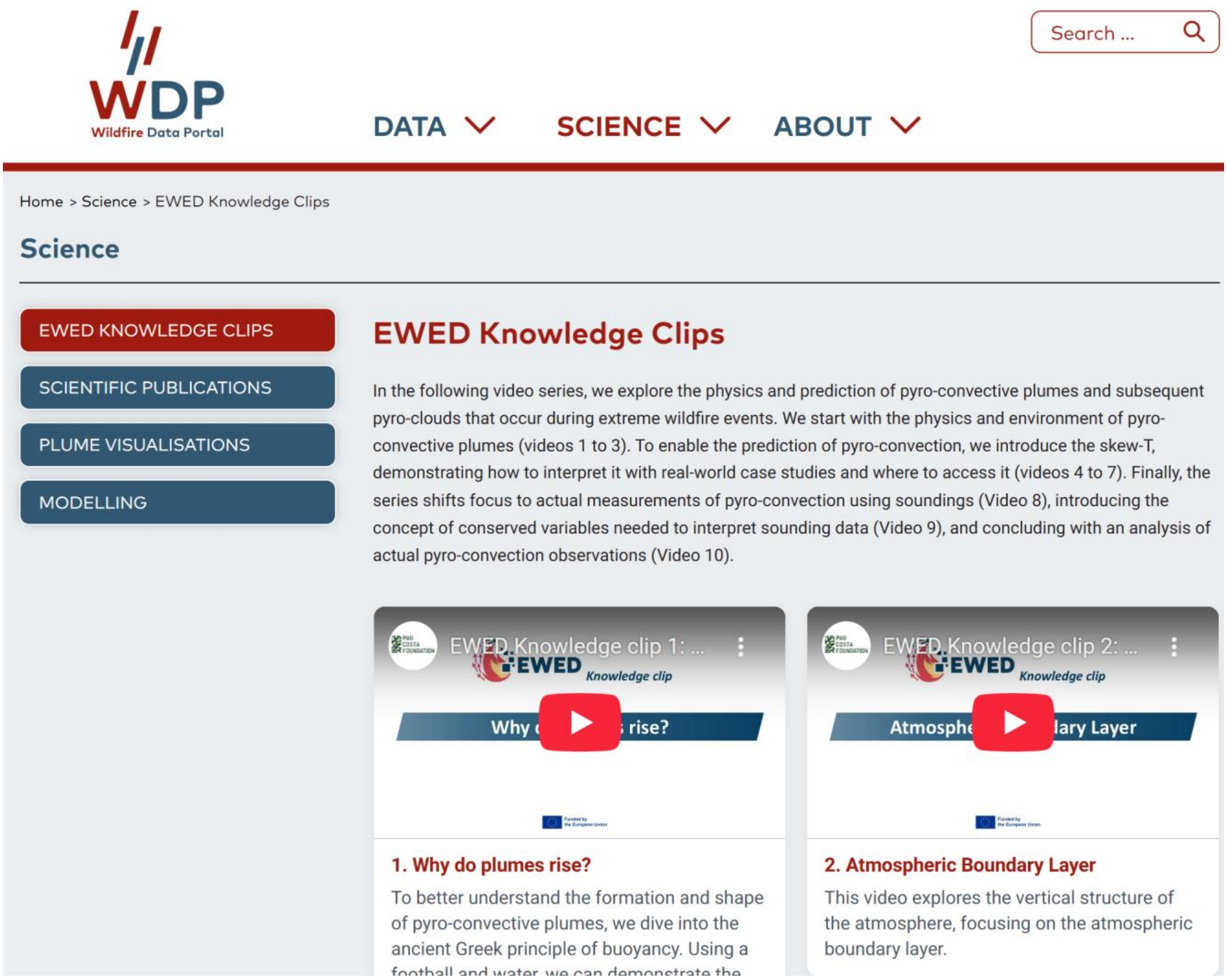

Figure 5 A screenshot of the webpage where the EWED Knowledge Clips can be accessed and viewed.

The second main part of the Wildfire Data Portal that will be described in this report is [the actual data portal itself](). Here, an overview of different wildfire cases is made available. For each wildfire case, as much data as possible is shared with open access. In principle, for each wildfire case, there is information about the fire behaviour available, hourly perimeters, together with photos of the fire or plume and a brief description of the fire itself. Radiosonde observations that are taken at the fire are also shared for each wildfire. Finally, related publications about the wildfire and, if available, CLASS model simulations are also shared.

These wildfire cases and their corresponding data can be used for various purposes. For example, they can be used to gain insight into the fire behaviour of these wildfires while comparing them to the conditions they occurred in. The open access data from the WDP can also be used for further scientific analyses.

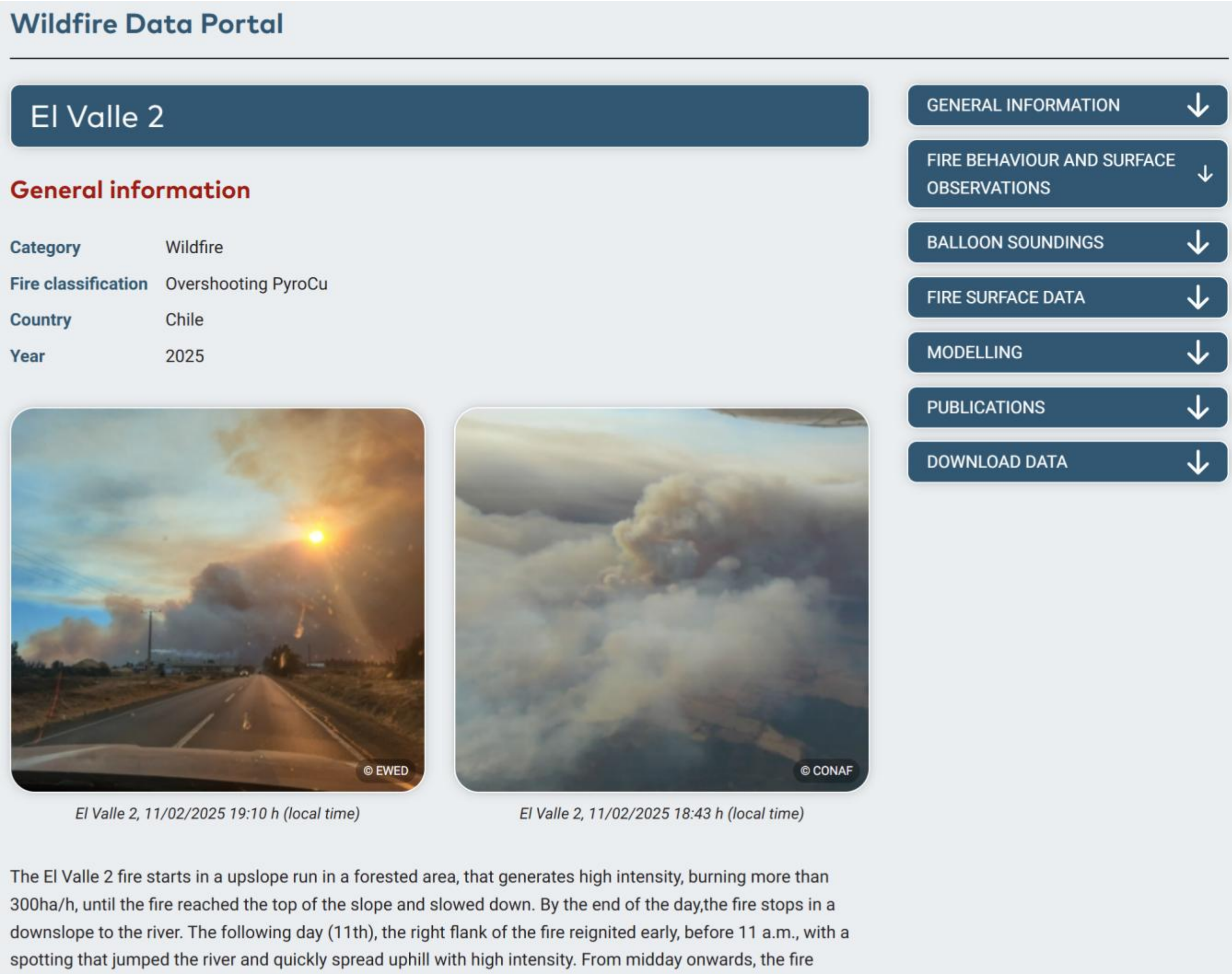

Figure 6 A screenshot of the webpage of one of the available wildfire cases (El Valle 2, Chile) that is available on the WDP.

2.6. International training and knowledge exchange

Finally, it is recommended to actively involve international trainings and knowledge exchanges. Such trainings or exchanges are important to prepare for EWEs because they can help bridge the gap between scientific insight and operational decision-making in uncertain and fast-evolving situations. The EWED Training Events demonstrated that bringing together researchers, fire analysts, incident commanders and other fire practitioners from different countries can help in creating a shared understanding of the complex fire-atmosphere interactions, plume dynamics and uncertainty management that is involved with EWEs [14].

Figure 7 Participants from Greece collaborate during an exercise of the in-person EWED Training Event using the CLASS model, supported by a member from the team of Wageningen University.

Importantly, trainings such as the EWED Training Events, can strengthen the interoperability of the newly gained knowledge and available tools as participants share a common professional language that is not limited by regional or national borders. Informal networking moments, collaborative exercises and shared reflections on real wildfire cases can enable practitioners to learn from diverse landscapes, fire regimes and organisational construction, while recognising that EWEs are an increasing risk, even in countries with a more limited historical experience with such events. Regularly organising and participating in such events is thus important to keep preparing for EWEs. Hence, such events should keep on being organised outside the EWED project in order to sustain the international knowledge exchange through reaching more fire practitioners whilst also allowing to stay up to date of the most recent knowledge.

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