



**FOREST FIRES ASSESSMENT AND
ADVISORY TEAM - SPAIN**

TECHNICAL REPORT

Alexandroupolis and
Dadia-Soufli forest fires
(Greece 2023)



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AUTHORS

FAST TEAM GREECE COMPOSITION

Iñaki Bustamante López-Chicheri (Team Leader)

ibustama@tragsa.es

Asier Larrañaga Ochoa de Egileor (Deputy Team Leader)

asier.larra@gencat.cat

Miguel Ángel Botella (Fire Analyst)

miguelbotella@vaersa.com

Juan Manuel Galeote Cárdenas (Fire Analyst)

juan.galeote@juntadeandalucia.es

José Luis García Fernández (Fire Analyst)

joseluis.garcia@gencat.cat

Víctor Riera Jimenez (Fire Analyst)

vriera@tragsa.es

Daniel Samper Sánchez (Operations, S&S Officer)

dsamper@bombersdv.es

Gonzalo Muñoz Pérez (Logistics)

gmunoz5@tragsa.es

MISSION

Destination:

Alexandroupolis and Dadia-Soufli
Greece

Duration:

From 17 September to 6 October 2023
From 18 to 22 September in the field

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FRONT PAGE

Overview of the forest fire of Alexandroupolis.

Photo credit: Seasonal Firewatcher of Lefkimis region Mr. Domakinis Christos

DISCLAIMER

The contents of this technical report are the sole responsibility of the authors. They do not reflect the views of the European Union, the Greek National Government or its Local Authorities.

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EXECUTIVE SUMMARY

- The Alexandroupolis forest fire started on 19th of August. A second ignition in the area occurred in Dadia-Soufli on the 21st. The burnt area ended up in a final estimated area, according to Copernicus, of **93,880 ha**. This is the largest forest fire ever recorded in the EU.
- The Dadia-Soufli ignition run on the 21st, which, in a period of approximately **13 hours, travelled 50 km** at an average speed close to **4 km/h**, is the main factor that explains the final size of the fire. In this period, the fire **grew by approximately 30.000 ha**, and increased the perimeter by **more than 130 km**. On consecutive days and still under adverse weather conditions, the fire grew mainly based on re-openings on the right flank, which presented complex orography and forest structures that made suppression tasks extremely difficult, if not impossible.
- The behaviour of the fire that was originated in Dadia-Soufli on the 21st was characterised by the convective activity that the smoke column developed, with spotting fires **jumping from 200 to 500 metres** and pulsations at the head with propagation speed ratios greater than **5-6 km/h**. The estimated average flame lengths at the head were over **40 metres** with about **90,000 Kw/m** of front intensity. These fire behaviour values were outside the suppression capacity of any forest fire or emergency service. The relevant aspect about this case is that the fire was also capable of maintaining the same fire behaviour during the night, making it impossible to fulfil control manoeuvres that fire services can usually carry out with more favourable night conditions. Fires that maintain convective activity during the night are rare but seem to have a tendency to increase, as shown by the examples of violent nocturnal spreads in Ateca (Spain 2022) and Santa Ana (Chile 2023) with similar atmospheres governing the fires.
- The general scenario was characterised by very severe meteorological conditions, with strong wind intensity, dry air mass and instability in the upper layers of the atmosphere. The moisture of the live fuels was low with a clear trend towards desiccation in the previous days that also predisposed the dead fuels to burn at very high intensity. The vegetation also showed obvious signs of water stress with significant extensions of oak trees, as the most representative species, presenting dry leaves in the crown already in mid-August. The Alexandroupolis fire could affect such an important surface due to the large continuity of fuel available in the axis formed by the forest massif of Dadia, Aisymi and Makri.
- The main run of the August 19th ignition in Alexandroupolis was towards the coast, where most of the forest-urban interface and communication infrastructure were concentrated. The impact of the head of the fire against vulnerable elements forced the suppression system to adopt a defensive strategy for



the protection of people and properties, allocating most of the resources in this task. The concentration of resources on protection tasks allowed the fire to open the flanks, generating new runs towards the urban area and a permanent demand for new resources to protect newly affected vulnerable elements.

- All these conditions generated a favourable framework for the development of fires beyond the suppression capacity. These kind of scenarios represent a significant challenge for forest fires and emergencies services that must adapt to new strategies, in order to anticipate when this phenomenon will happen, what measures should be taken to protect the population and how are the suppression operations organized to be effective, and to avoid accidents.

BACKGROUND

Due to the wave of forest fires in Greece in the summer of 2023, and its consequences, the Greek Government requested the activation of the European Union Civil Protection Mechanism (UCPM) in order to provide additional expertise on the analysis of the fires of northeast Greece at the prefecture of Evros.

The Ministry for Ecological Transition and Demographic Challenge (MITECO) of the Spanish Government offered the registered and certified capacity Forest Fires Assessment and Advisory Team (FAST). The team mobilised for this assessment mission was integrated by eight forest fires experts in the areas identified in the terms of reference of the request: fire behaviour analysis and operations experts.

The main objective of the UCPM is to facilitate the cooperation in disaster prevention, preparedness and response among its 35 participating States (EU-27 and the Republic of North Macedonia, Iceland, Norway, Serbia, Montenegro, Turkey, Bosnia and Herzegovina and Albania).

For this mission, the terms of the reference were:

- Location: Alexandroupolis (Greece).
- Dates: 17 September to 2 October 2023 (16 days). Five of them in the field.
- Goals: Analysis of two large fires near Alexandroupolis.
Provide a technical report for the Greek Government.
- Expert's experience: Fire behaviour analysis. Operations, at tactical and strategic level.
- Logistics: Covered by FAST self-sufficiency and Greece Host Nation Support.

The FAST team arrived in Athens on the 17th of September. From Monday 18th to Friday 22th, the team attended different meetings with actors involved in the emergency: from Incident Commanders to General Secretary of Civil Protection, and other relevant representatives of the Hellenic Fire Service. In these meetings, lots of information, documents, photos and videos of the Alexandroupolis and Dadia-Soufli fires were shared with the team. Between 19th and 21th of September, the FAST team travelled to Alexandroupolis visiting different areas



in both forest fires. During the visit to Alexandroupolis, the FAST team met the Incident Commanders and the Chief of Hellenic Fires Service of prefecture of Alexandroupolis. On the 24th, the FAST team travelled back to Spain. The development of this technical report started once the team was activated, before arriving to Greece, analysing the already available information, and continued until the report was finalized, after returning from Greece.

TARGET GROUP, AIMS AND STRUCTURE

This technical report is primarily addressed to the national authorities of the Government of Greece, to the UCPM but also to the entire global forest fire community to be able to learn from this natural disaster.

The objective of this technical report is to analyse and diagnose what happened in the Alexandroupolis fire based on the available data and existing information at the moment of the assessments, as well as the FAST experts' observations of the terrain, knowledge and experience.

The second objective, related to the emergency response, is to draw some preliminary findings in case that similar events may occur in the future, also in other parts of Europe and the world.

This technical report describes the previous situation of the vegetation and the meteorological factors affecting the fire behaviour, reconstructs in detail the development and affection of the fire and reflects the preliminary findings.

As a result of this process, there are a number of recommendations on fuel management together with firefighting operations that should not be considered exhaustive or definitive, given the limited timeframe of the mission.



METHODOLOGY

The main goal of the report is to analyse the fire behaviour and this has to be made by estimating the rate of spread and the length of the perimeter as accurate as possible. This makes possible to know what was affected by the fire (towns, highways, structures, electric lines, etc.), and when.

Isochrones reflect the line of fire perimeters that are active at the same time. By knowing isochrones, it is possible to determine the fire evolution, rate of spread or flame front velocities. To extract the different hourly isochrones of Alexandroupolis and Dadia-Soufli forest fires, the FAST team worked on all the videos and pictures provided by the Hellenic Fire Service, taken by the aerial coordinators and other firefighters involved in operations.

The methodology consisted in sorting chronologically all the videos and pictures using the metadata that includes the date and hour when they were taken and comparing them with the temporal logic.

The next step was to look for different physical elements, such as roads, towns, firebreaks, crop areas, lakes, etc., and to draw the fire line on cartography (Google Earth). When putting together all the lines within the same timeline, an estimated polygon was constructed. This polygon represents the perimeter of the forest fire at a given time. With a sequence of different perimeters, the evolution of the forest fire is specified, and its temporal chronology is established. Through interviews to firefighters involved in operations, the outcome was confirmed to be correct. Finally, each perimeter was designated with the date, time, and location (right or left flank) of the corresponding forest fire.

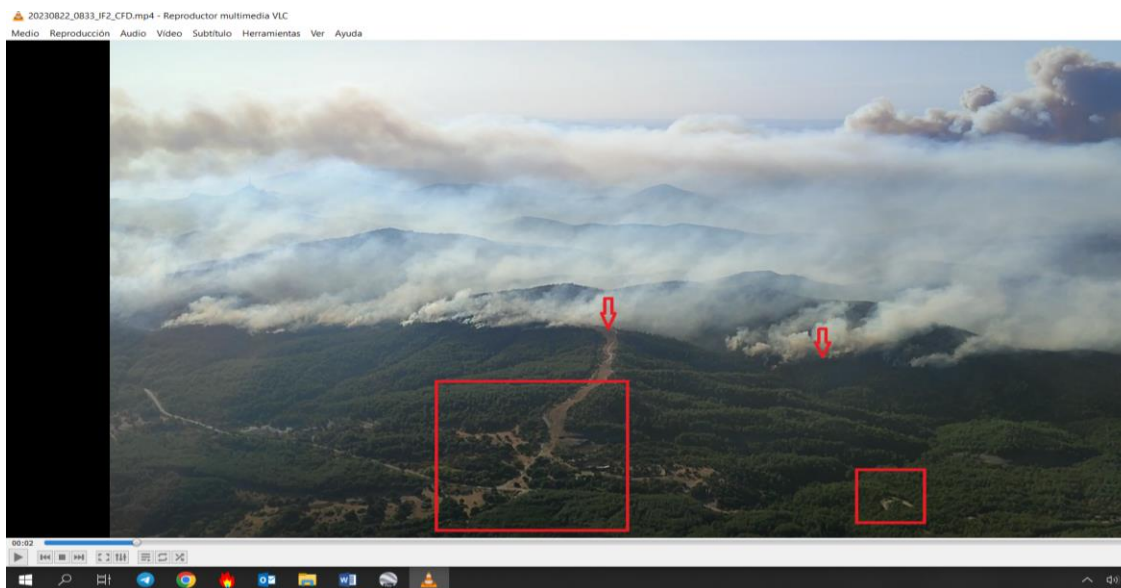


Figure 1 Example of identification of recognisable elements using videos.



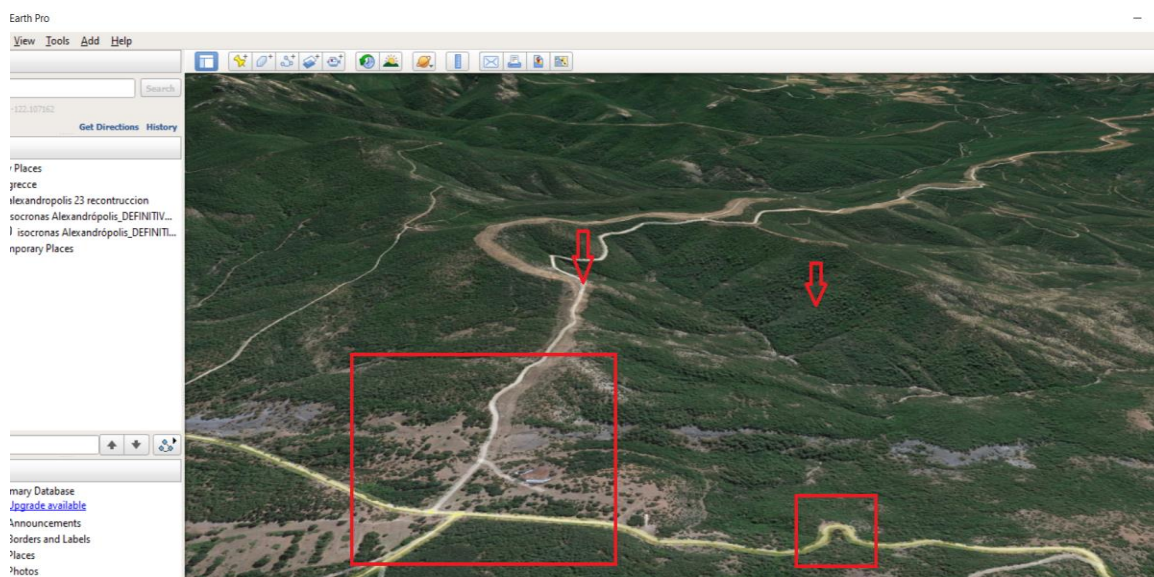


Figure 2 Example of identification of recognisable elements using cartography.

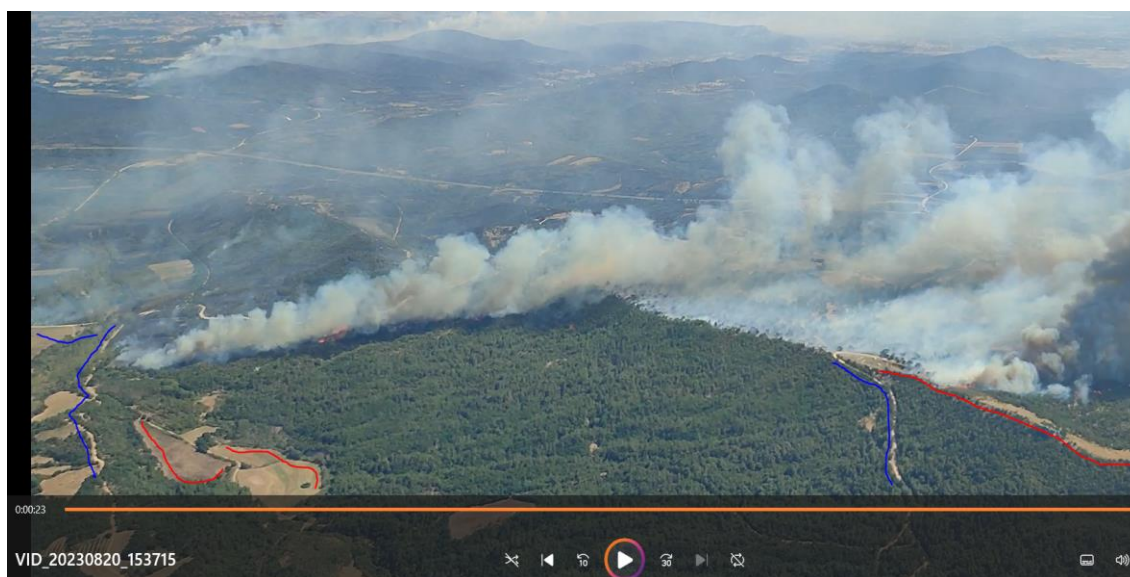


Figure 3 Example of identification of recognisable elements using videos.



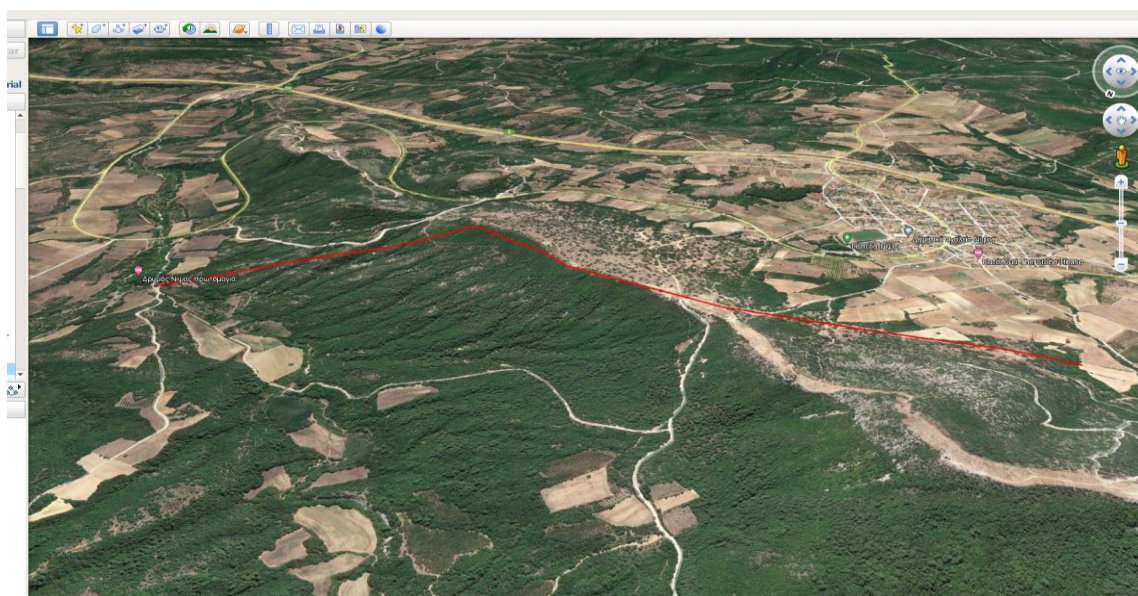


Figure 4 Perimeter drawn on cartography.

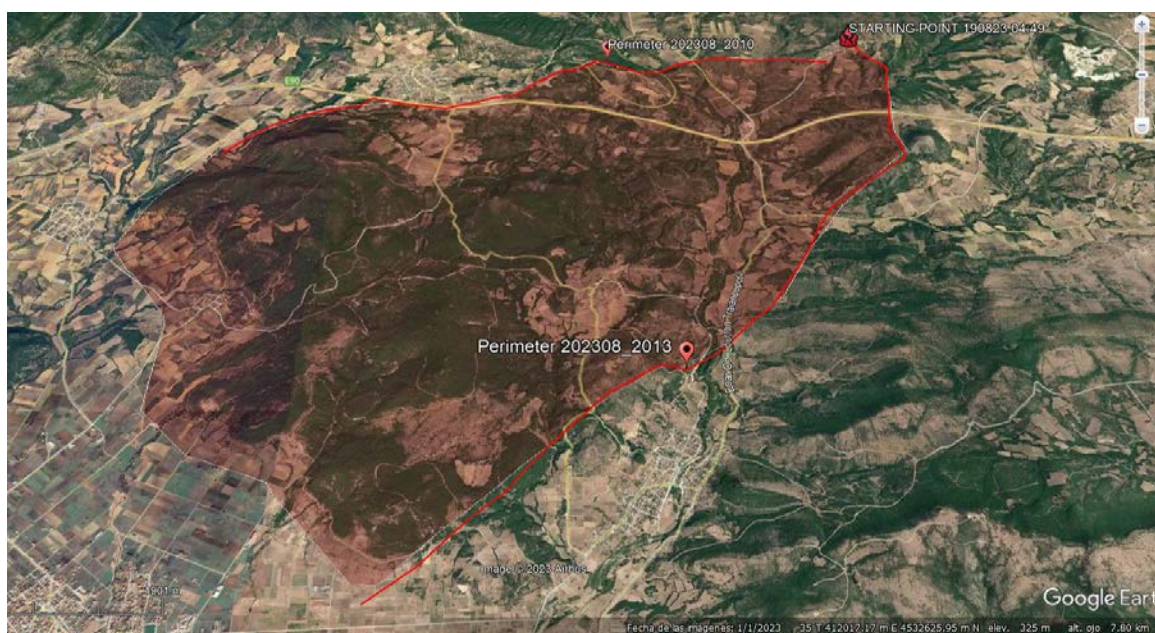


Figure 5 Resulting polygon according to the estimated perimeters.



The next figure shows the different polygons of the forest fires of Alexandroupolis between its start on the 19th and the 21th of August at 12:30 hours (local time). The evolution of the fire can be observed according to the isochrones.

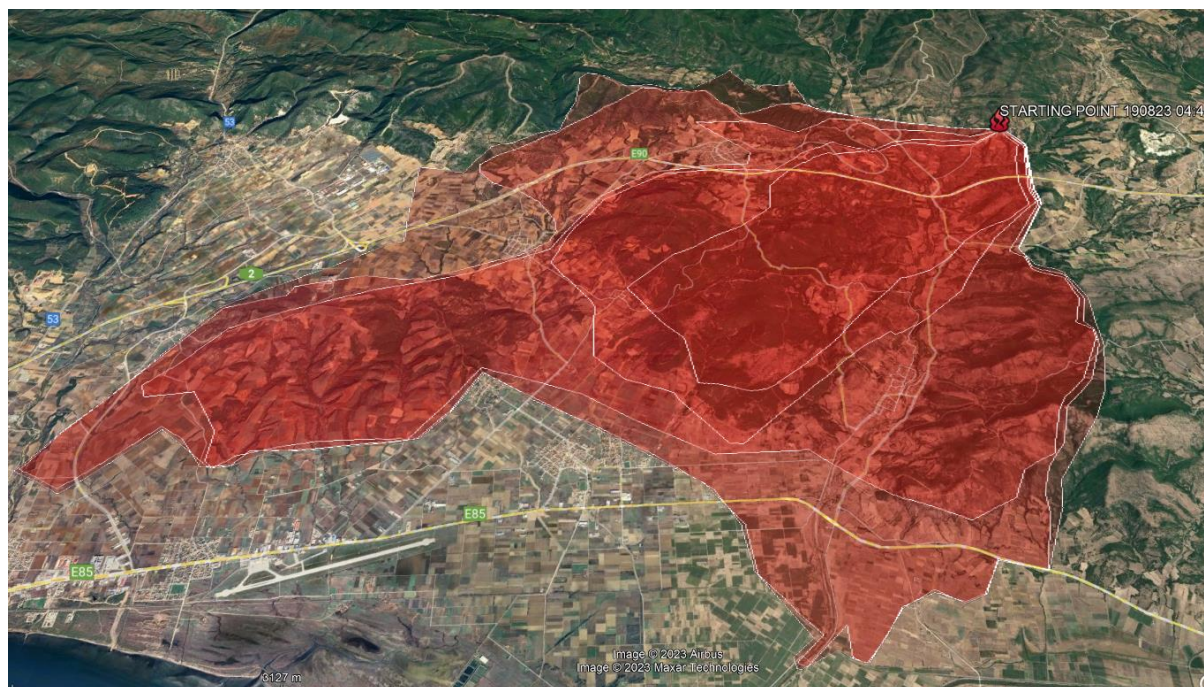


Figure 6 Different polygons showing fire perimeters of Alexandroupolis fire.



ANALYSIS AND PRELIMINARY FINDINGS

PRE-FIRE SITUATION

There are two main factors to be considered for the development of the fire: forest structure and fuels availability (vegetation available to burn). The description of these factors in the area where the Alexandroupolis fire occurred, using various indicators, reveals the potential of the fire behaviour.

One of the keys in the spread of the fire was the **continuity of the forest stand**, even when there is a diversity of species. In this case the fuel models with the greatest presence in the area of the fire are those dominated by the tree stratum mostly with scrub subfloor, which correspond to models "Deciduous Broadleaf Closed Forest", "Shrub Medium" and "Crop Herbaceous" according to FirEurisk Fuels Classification System (Aragoneses et al., 2023). The undergrowth models under the trees are composed of *Quercus sp.*, *Pinus sp.*, *Juniperus sp.*, *Festuca sp.* and *Stipa sp.* with a fraction of tree cover between 60-80%. In several areas there are still extensive and fully developed kermes oak forests (*Quercus coccifera*), representing a degraded stage of a thermophilic deciduous forest (*Quercus pubescens*, *Quercus cerris* and *Quercus frainetto*), due to its resistance to fire, grazing, pressure and its ability to resprout after cutting. The result is forest stands with a closed structure, usually with a high shrub load from *Juniperus sp.* and *Quercus coccifera*, both with a mean height of 2-3 m, under a canopy of different *Quercus* species, which were around 4-5 m in height. These types of forests present a very important vertical and horizontal fuel continuity (Figure 7) and conform a structure which is very vulnerable to crown fires and can generate enough intensity to sustain crown runs almost permanently, regardless of the terrain orography.



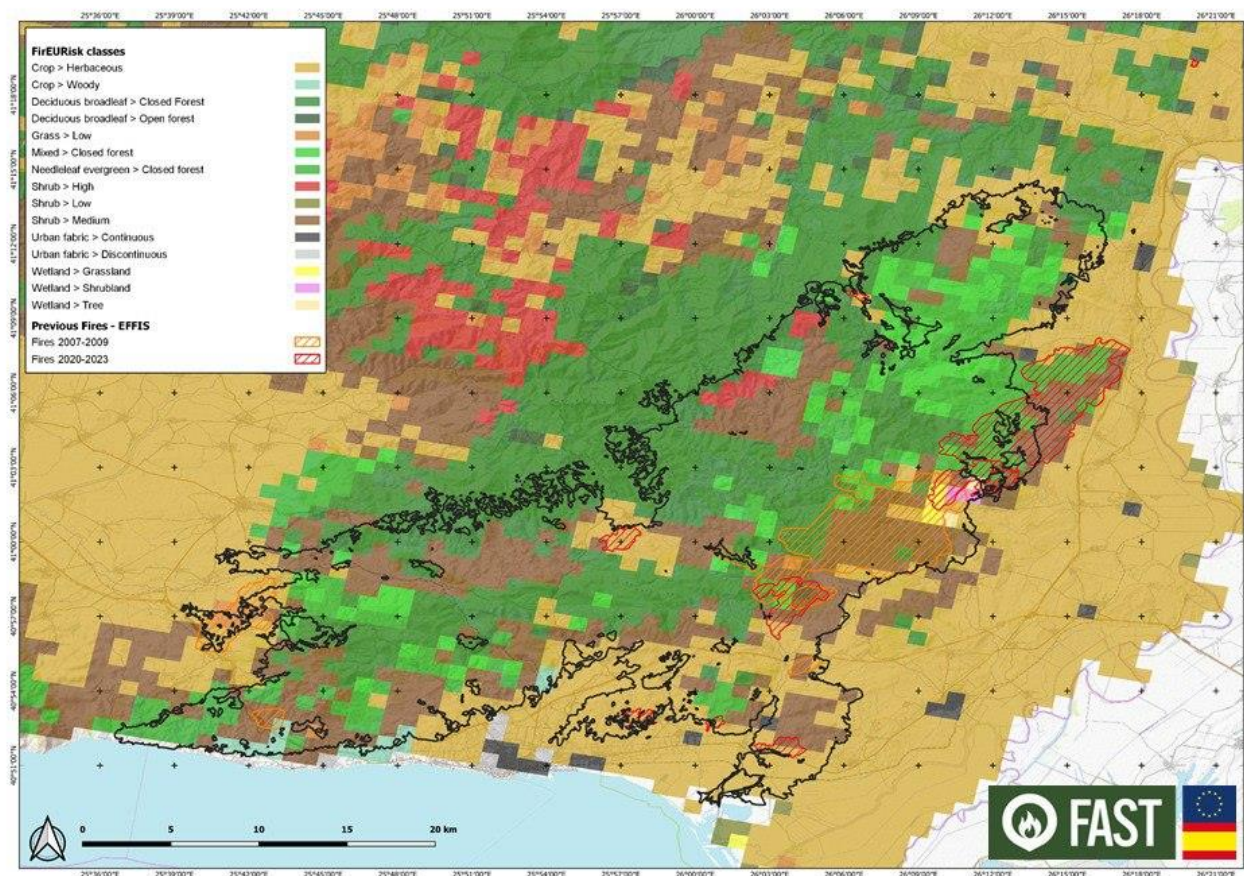


Figure 7 Vegetation distribution according to FirEURisk class and previous fire.

Another main factor considered for the development of the fire is the availability of the vegetation to burn: **the fuel availability**, which is determined by previous meteorological conditions, and the response of the plants to this stress factor. Precipitations during the previous months to the fire, as well as during August, have been significantly lower than previous years (Figure 8). This pattern of lack of precipitation is similar to the years 2000, 2003, 2007, and 2012.



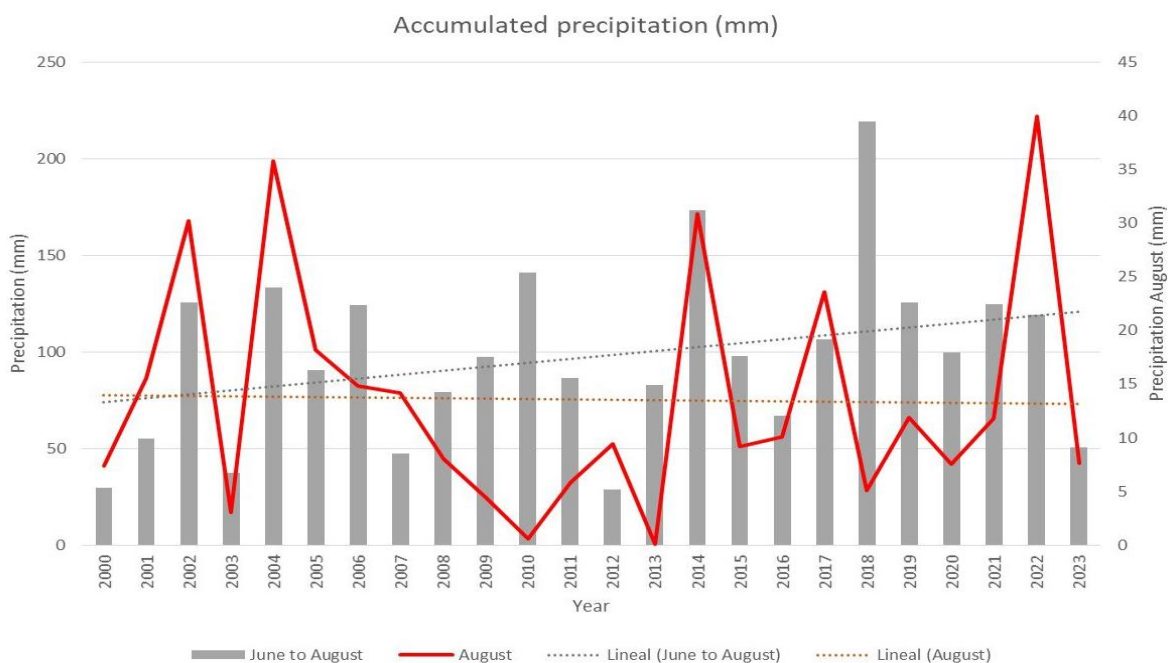


Figure 8 Accumulated precipitation (mm) June to August, and August, from ERA-5 database for the fire area.

Together with the lack of precipitation, there is a steady increase of temperature. Greece is no exception to this fact and the mean temperature rises every year (Figure 9). During the previous months to the fire, as well as during August, the temperatures have been higher than previous years and similar to the situation in the years 2007 and 2012.



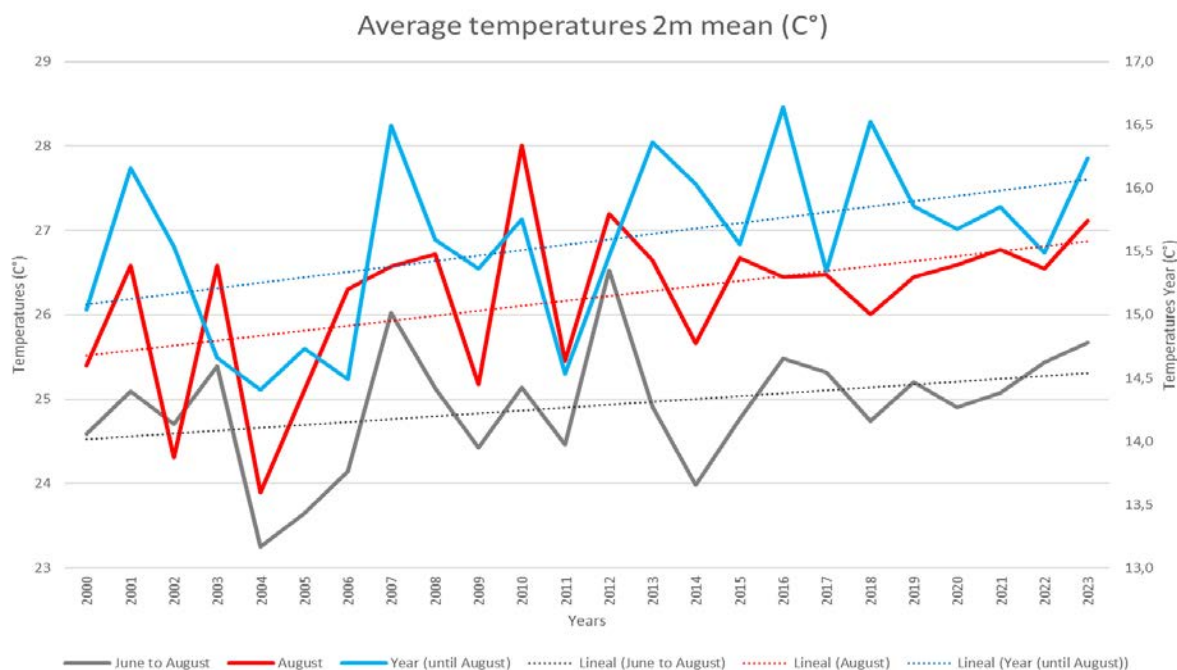


Figure 9 Average temperatures 2m mean from ERA-5 database for the fire area. Annual trend for different time periods.

This situation: generated by surface drying out, subsidence warming (several heatwaves) and drying of the atmosphere, left a favourable landscape to burn in high intensity. Through the study of the Vapour Pressure Deficit (VPD), which is an indicator that measures the difference between the water vapour content of the air and its saturation value, there is an accurate metric of the ability of the atmosphere to extract moisture from the land surface thus reflecting variations in the moisture content and flammability of forests.

VPD is more successful in explaining burnt forest fire area than other variables. It is more explanatory in this regard than RH (relative humidity) because it accounts for the fact that it is the combination of low RH (relative humidity) and high temperature that creates most of the fire-prone conditions.

Periods with extremely high VPD are expected to exert considerable water stress on vegetation, risking disease, fire and mortality. Hence, the assessment turns to examine the variability of VPD and its causes over the past August in the fire area. As can be seen in the following figure, the VPD values exceeded the critical thresholds, increasing even more during the fire event.



VAPOR PRESSURE DEFICIT | ALEXANDROUPOLIS FIRE

Vapor pressure deficit (VPD) is calculated as the difference between the amount of moisture that's actually in the air and the amount of moisture that air could hold at saturation. From a wildfire perspective, consistently elevated VPD means that ecosystems can more easily ignite and spread fire, leading to the larger, higher-severity wildfires that have ravaged forests in recent years.

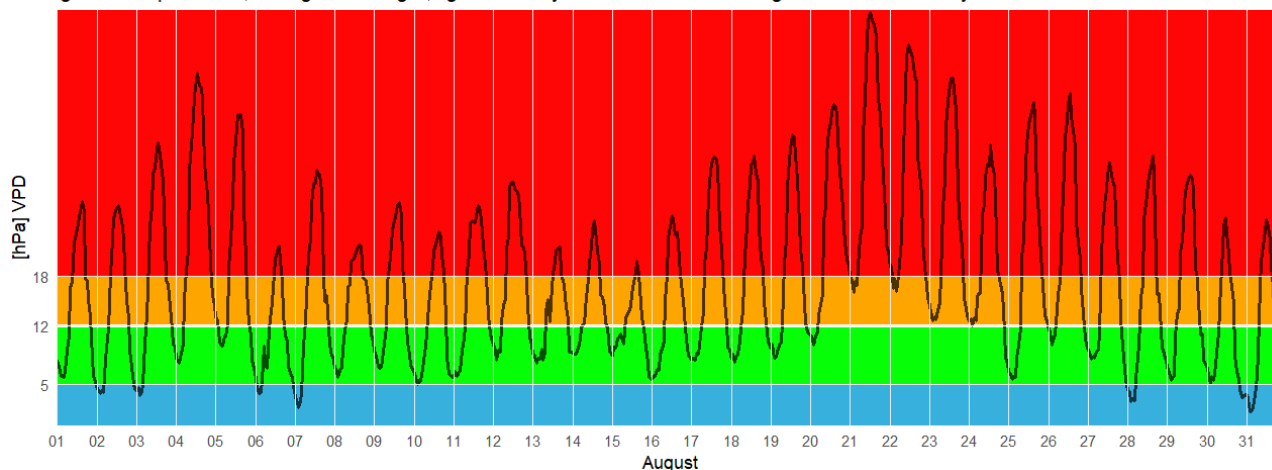


Figure 10 Evolution of VPD (Vapour Pressure Deficit) over the burnt area (August). Extreme dry atmosphere during the fires. Processed by FAST team Greece-2023.

Fuel moisture is one of the key drivers in wildfire dynamics. Direct measurement of the moisture content of live and dead fuels is a very costly task both in terms of resources and time. However, there are indirect ways to estimate these parameters, and to correlate them with the fuel's availability to the fire.

The following figure indicates how conducive water content in the biomass to fire ignition is. The layer represents the % moisture content of so-called dead fuels calculated based on temperature and relative air humidity. The method of calculation is based on the *Predicting dead fine fuel moisture at regional scales using vapour pressure deficit from remotes sensing's and gridded weather data* (Nolan et al., 2016). The 10-hour dead fuel moisture corresponds to the moisture of standard fuel defined as smaller diameter dead branches between 0.25" and 1" in diameter (ca 0.6-2.5cm). This type of fuel can respond quickly to changing weather conditions and ignites relatively easily.

The calculated values typically range from 1% to 35%; with ignitions generally occurring when values drop below 15%. As dead fuel moisture decreases below 15%, the fire danger increases. Values below 6% are indicators of possible extreme fire behaviour.

Regarding dead fuels, an estimation based on water vapour pressure deficit has been used (Nolan et al., 2016).



DEAD FINE FUELS MOISTURE CONTENT | ALEXANDROUPOLIS FIRE

Definition of critical moisture thresholds for dead fine fuels (DF) according to Boer et al. (2017).

Relationship between availability categories of dead fine fuels, critical fuel moisture values and their colorimetric representation.

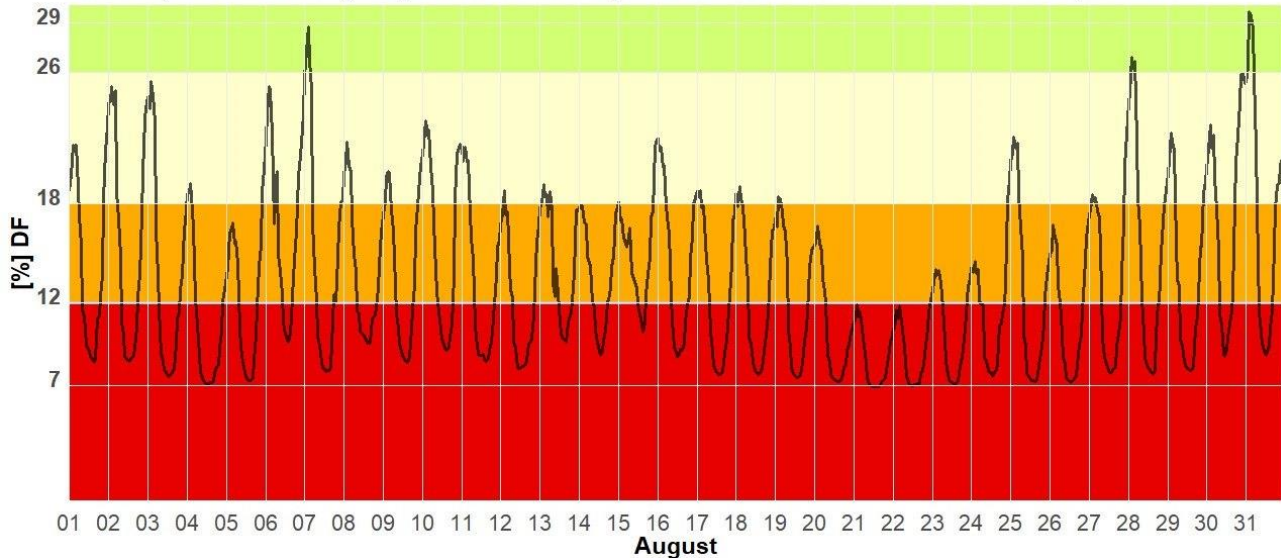


Figure 11 Dead fine fuels moisture content. Processed by FAST team Greece-2023.

The chart above shows the daily evolution of dead fine fuel moisture values during the month of August for the study area. As it can be seen, midday values were quite low in the days prior to the fire. Also noteworthy is the lack of recovery of moisture values during nighttime hours on the days of the fires, especially on the 21st and 22nd.

In relation to live fuels, a recently developed remote sensing product based on MODIS imagery has been explored (Cunill Camprubí et al., 2022). As it can be seen in the next figure, live fuels had been progressively losing moisture during the month prior to the start of the fires in the Alexandroupolis area, remaining at values quite prone for fire propagation.



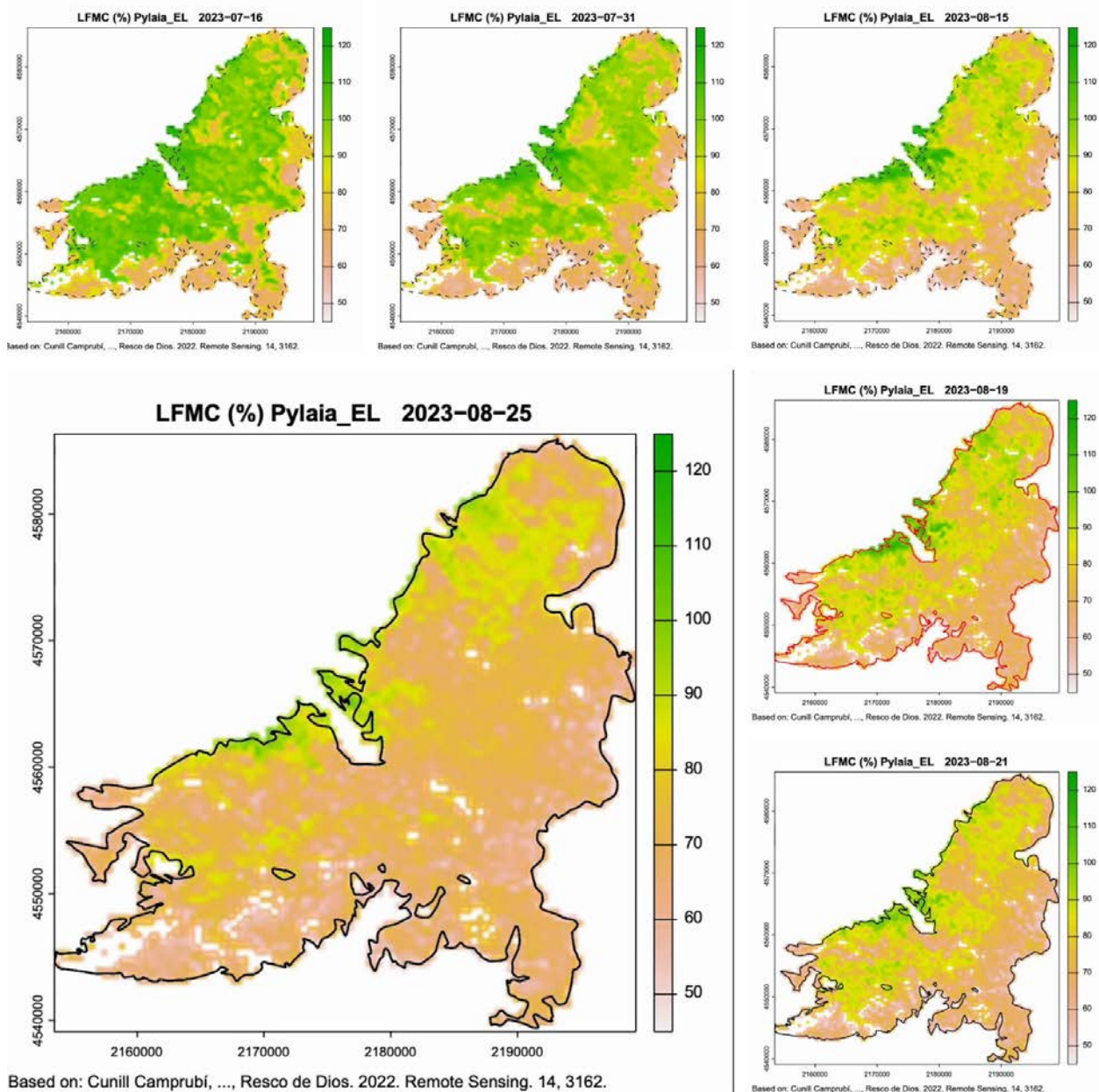


Figure 12 Evolution of LFM (Live Fuel Moisture Content) over the burnt area the previous days to the start of fires.

In addition, fire weather conditions were estimated using the Hot-Dry-Windy Index (HDW). Low values of ambient moisture, coupled with intense winds, increase the likelihood of severe fire behaviour. The HDW (Srock, et al., 2018) was designed to help users determine which days are more likely to have adverse atmospheric conditions that make more difficult wildfire management. It was designed to be very simple – a multiplication of the maximum wind speed and maximum vapour pressure deficit (VPD) in the lowest 50 or so millibars in the



atmosphere. Because HDW is affected by heat, moisture, and wind, seasonal and regional variability can be found when comparing HDW values from different locations and times. Higher values of the index (especially above 400) indicate severe conditions in which fires can spread quickly and intensely. Maximum values of the index can be observed for the 21st and 22nd of August.

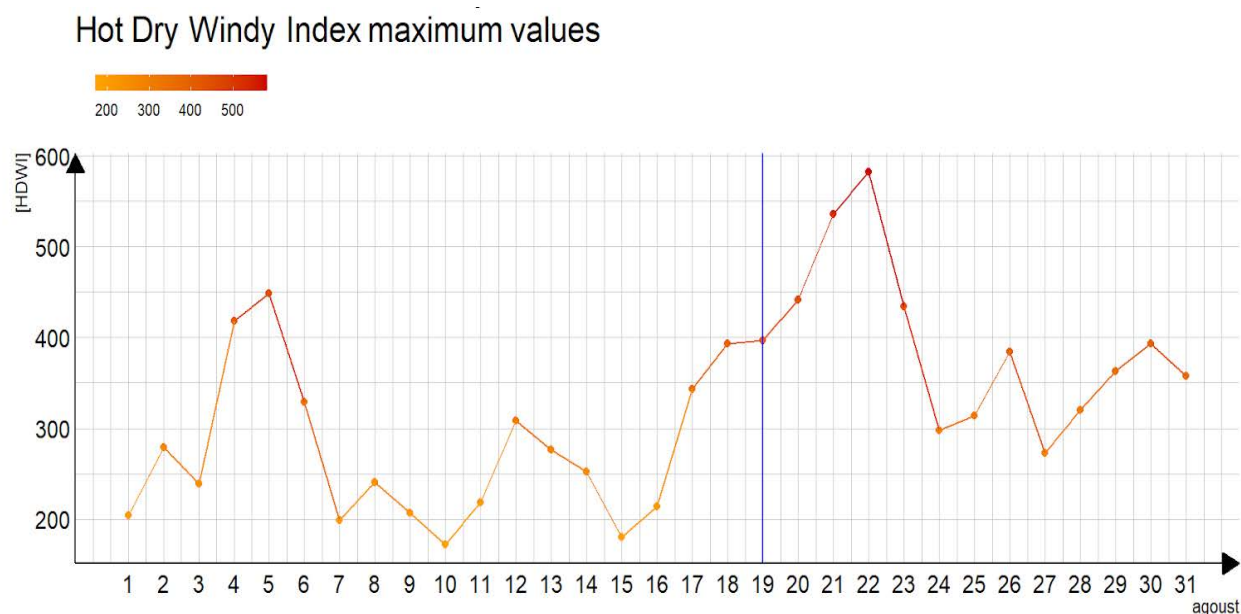


Figure 13 Daily evolution of the Hot-Dry-Windy Index (HDW) in August for the Alexandroupolis fire area. Maximum values can be observed for August 20th and 22nd.

The standardised precipitation evapotranspiration index (SPEI) offers near real-time information about drought conditions at the global scale. The dataset is updated during the first days of the following month based on the most reliable and updated sources of climatic data. SPEI fulfils the requirements of a drought index since its multi-scalar character enables it to be used by different scientific disciplines to detect, monitor and analyse droughts. The SPEI can measure drought severity according to its intensity and duration, and can identify the onset and end of drought episodes. The SPEI allows comparison of drought severity through time and space, since it can be calculated over a wide range of climates, as can the SPI. Moreover, (Keyantash & Dracup, 2002) indicated that drought indices must be statistically robust and easily calculated, and have a clear and comprehensible calculation procedure. All these requirements are met by the SPEI. However, a crucial advantage of the SPEI over other widely used drought indices that consider the effect of PET (potential evapotranspiration) on drought severity is that its multi-scalar characteristics enable identification of different drought types and impacts in the context of global warming.

This graphic shows the evolution since 2015 of the SPEI index in the area of the fire, reflecting the severe conditions the vegetation was suffering and the availability of fuels.



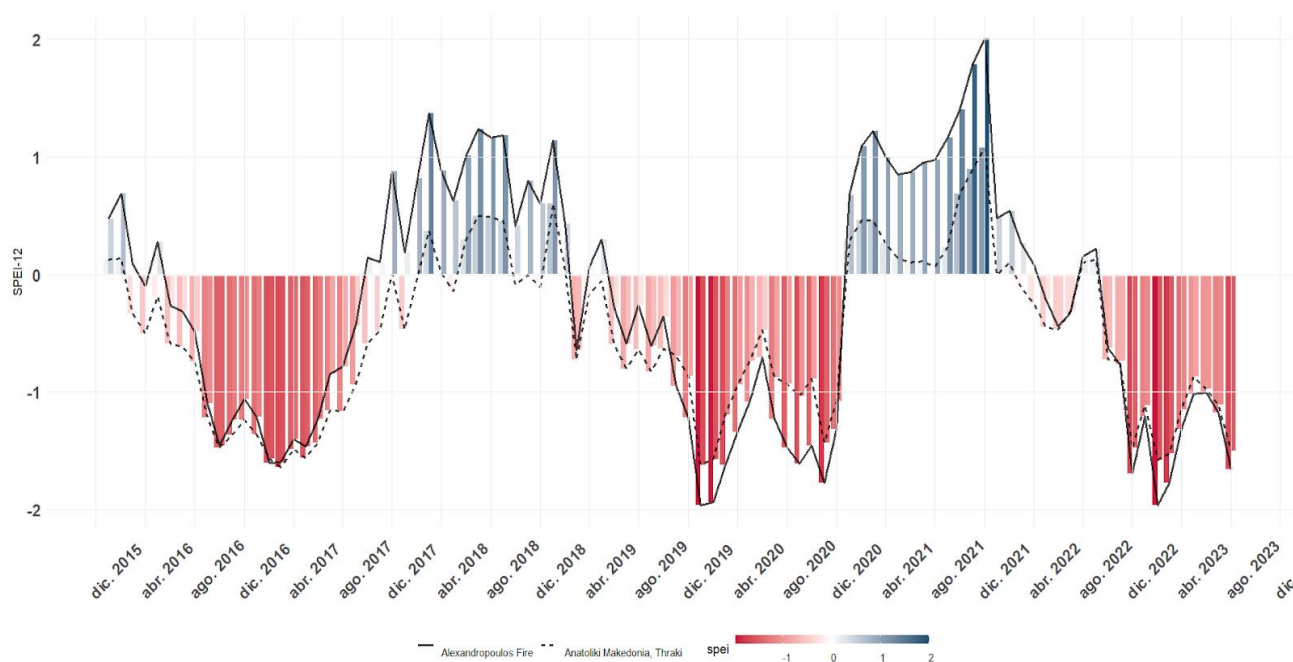


Figure 14 SPEI evolution. Data: SPEI Global Drought Monitor.

All the indicators and graphs analysed in this chapter indicate severe conditions in the area where the fire started and explain the observed fire behaviour.

FIRE RECONSTRUCTION

The Alexandroupolis fire developed over a period of about 15 days, starting on the 19th of August, that were determined by:

- A more active phase of perimeter growth between the 19th and the 24th of August.
- Followed by a quieter period until the 30th of August.
- And the final growth with the passage of the front marked by the spread in a north easterly direction.

The most outstanding moments, which are described in greater detail, from this point forward, are focused between the 19th and 22nd of August because they determined the final outcome of the fire. Within this period, the most relevant propagation process occurred between 13:00h on the 21st and 08:00h on the 22nd (both local time), determined by the start and development of the Dadia-Soufli fire and the interaction with the



Alexandroupolis fire, giving rise to the most extreme values of propagation speed and intensity of the front in a sustained manner.

August 19th

A fire breaks out about 1 km north of the Egnatía Odó freeway between Nipsa and Pylaia villages at 04:49 am. Suppression resources are sent from the beginning of the fire and worked throughout the morning without achieving stabilization.

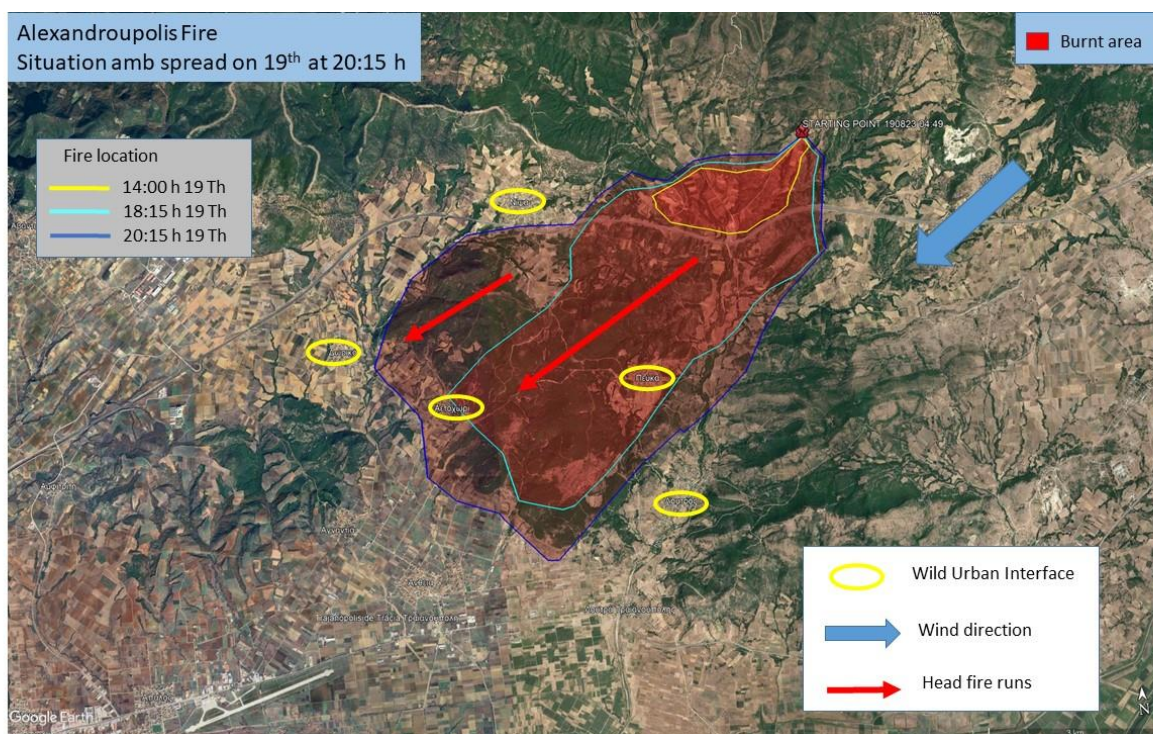


Figure 15 Evolution of the fire throughout the 19th with perimeter isochrones at 14:00 h, 18:15h and 20:15h.

Table 1 Weather conditions forecasted at 19/08/2023 at 02:00 UTC, 05:00h local time by the ECMWF model.

Wind speed	30-35 km/h
Wind direction	N-NE
Temperature (2m)	23°C (approx.)
RH	58% (approx.)



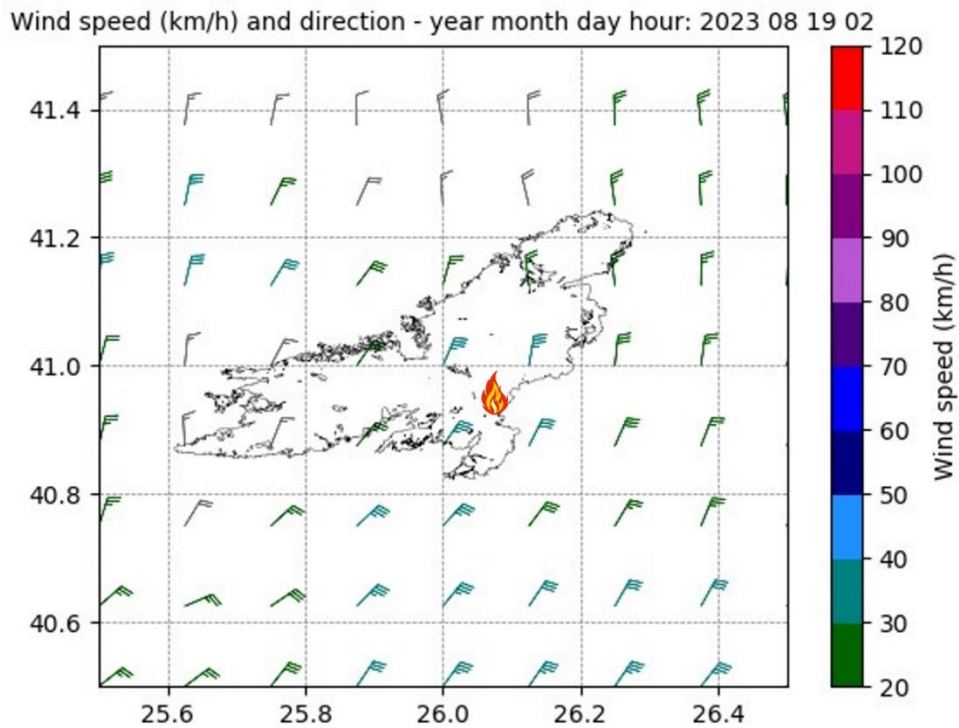


Figure 16 Wind conditions from ECMWF model for 19/08/2023 at 02:00 UTC (05:00 local time).

The Alexandroupolis Airport weather data shows that the wind at **02:50 UTC** was NE (28 km/h), which correlates quite well with the model forecast considering the slight difference in geographical location and surface height between the airport and the fire starting point.

Regarding the atmospheric profile, the ECMWF model shows a very unstable layer from the Convective Condensation Level (CCL) at 700 hPa to the Equilibrium Level (EL) at 300 hPa. Nonetheless, that unstable layer was not accessible by the fire plume due to a very stable layer existing below the 800 hPa level. The fire was spreading within the conditions of this stable and humid layer and its behaviour, reported by the Incident Commander on-site that day, was compatible with those conditions.



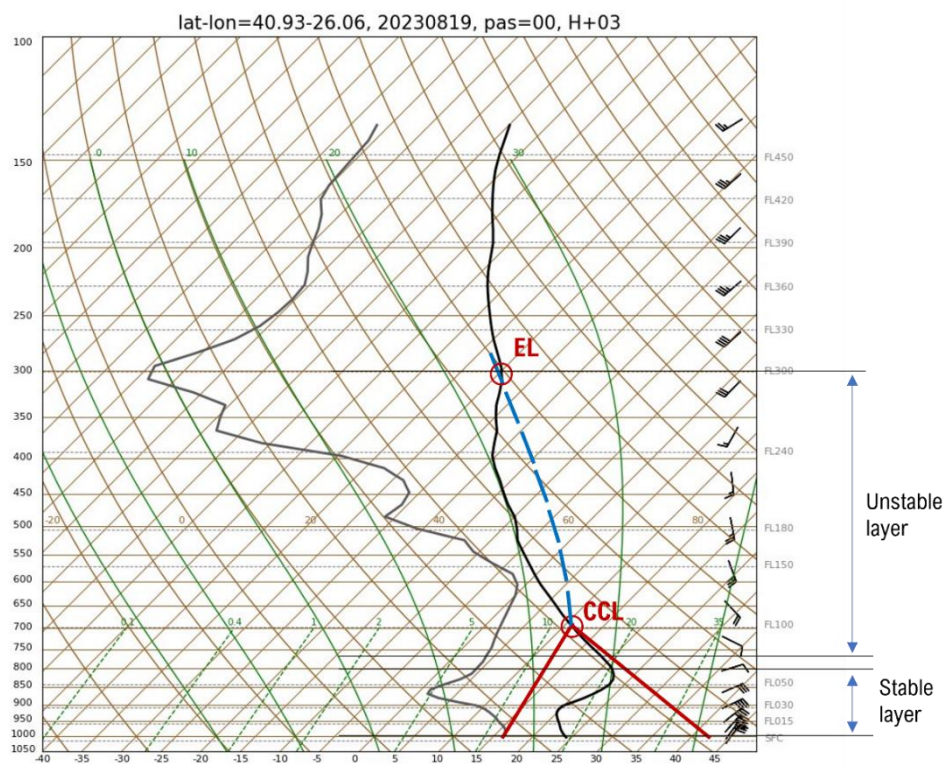


Figure 17 ECMWF model sounding for 19/08/2023 at 03:00 UTC (06:00 local time).

Table 2 Weather conditions forecasted at 19/08/2023 at 03:00 UTC, 06:00h local time by the ECMWF model.

Wind speed	30-35 km/h
Wind direction	N-NE
Temperature (2m)	25°C (approx.)
RH	47% (approx.)



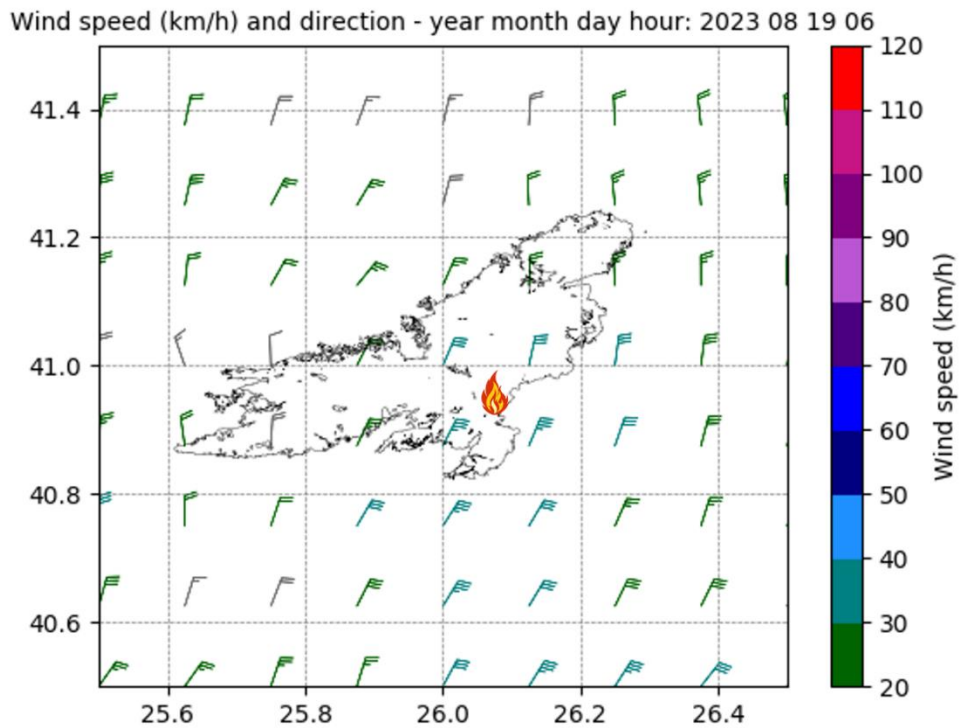


Figure 18 Wind conditions from ECMWF model for 19/08/2023 at 06:00 UTC (09:00 local time).

The Alexandroupolis Airport weather data shows that the wind at **06:00 UTC** was NE (30 km/h with 48 km/h gusts), also in good correlation with the forecast model.

The 06:00 UTC ECMWF model atmospheric profile is similar to the 03:00 UTC one, but with one slight difference: the boundary layer now shows mild unstable characteristics up to the 950 hPa. Not enough to cause big changes in fire behaviour, but it is nonetheless starting to signal a change in the atmospheric structure. Strong instability still remains in the upper layers, but unavailable to the fire due to the deep stable layer in the middle acting as a cap. Ambient moisture and temperature are still below the usual threshold for aggressive fire characteristics.



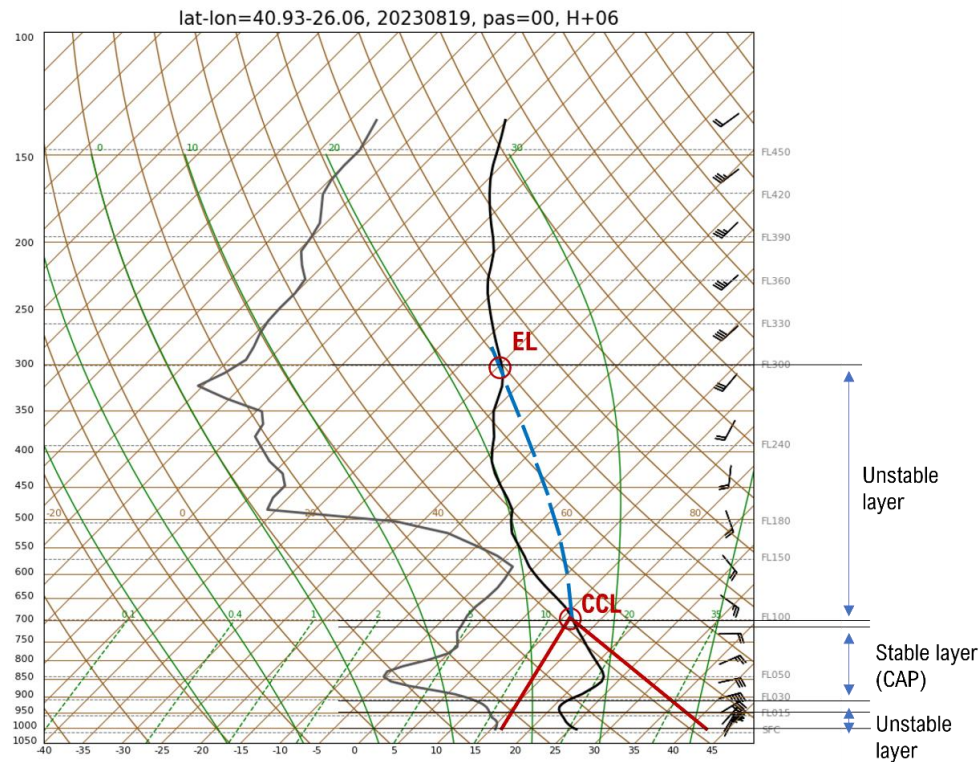


Figure 19 ECMWF model sounding for 19/08/2023 at 06:00 UTC (09:00 local time).

Table 3 Weather conditions forecasted at 19/08/2023 at 06:00 UTC, 09:00h local time by the ECMWF model.

Wind speed	35 km/h (gusts up to 50-60 km/h)
Wind direction	NE
Temperature (2m)	32°C (approx.)
RH	30% (approx.)



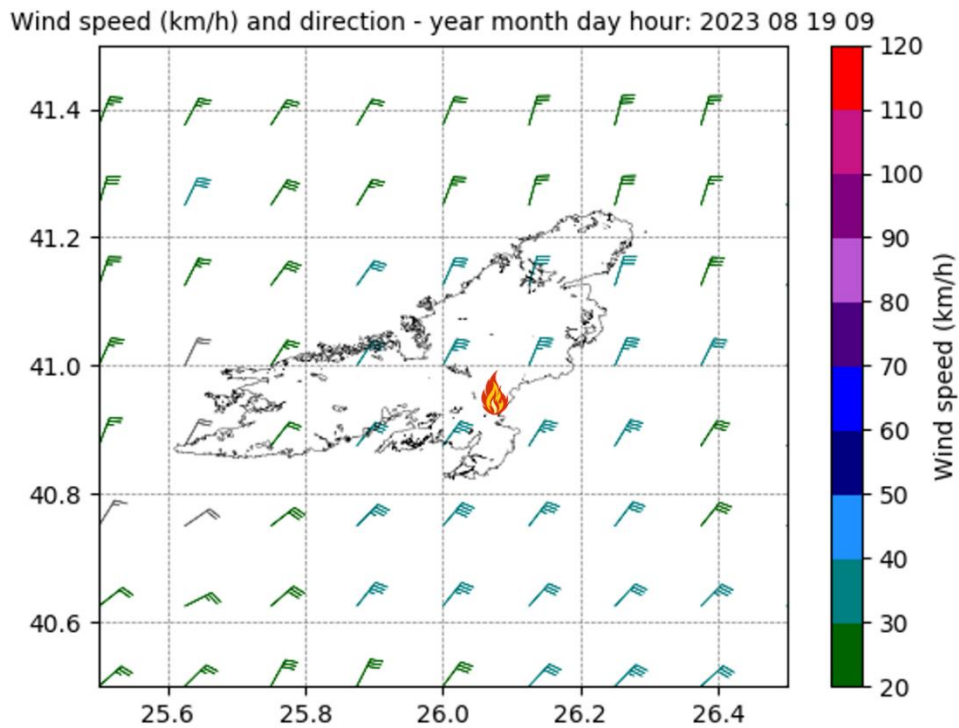


Figure 20 Wind conditions from ECMWF model for 19/08/2023 at 09:00 UTC (12:00 local time).

The Alexandroupolis Airport weather data shows that the wind at **09:00 UTC** was NE (37 km/h with 54 km/h gusts), also in good correlation with the forecast model.

As can be seen on the ECMWF model atmospheric profile, instability in the boundary layer has increased and deepened up to the 890 hPa (approximately 1.100 m height). This means that the smoke plume has more room to develop vertically, and the fire can show more aggressive behaviour. Any further increase in surface instability is also going to increase fire intensity, which may surprise firefighters deployed on-site. At the same time, the stable layer acting as a cap is still too strong for the plume to access the convective energy stored above. The increase in temperature and the decrease in ambient moisture are also contributing to the building up of fire intensity, also increasing the likelihood of a change for the worse.



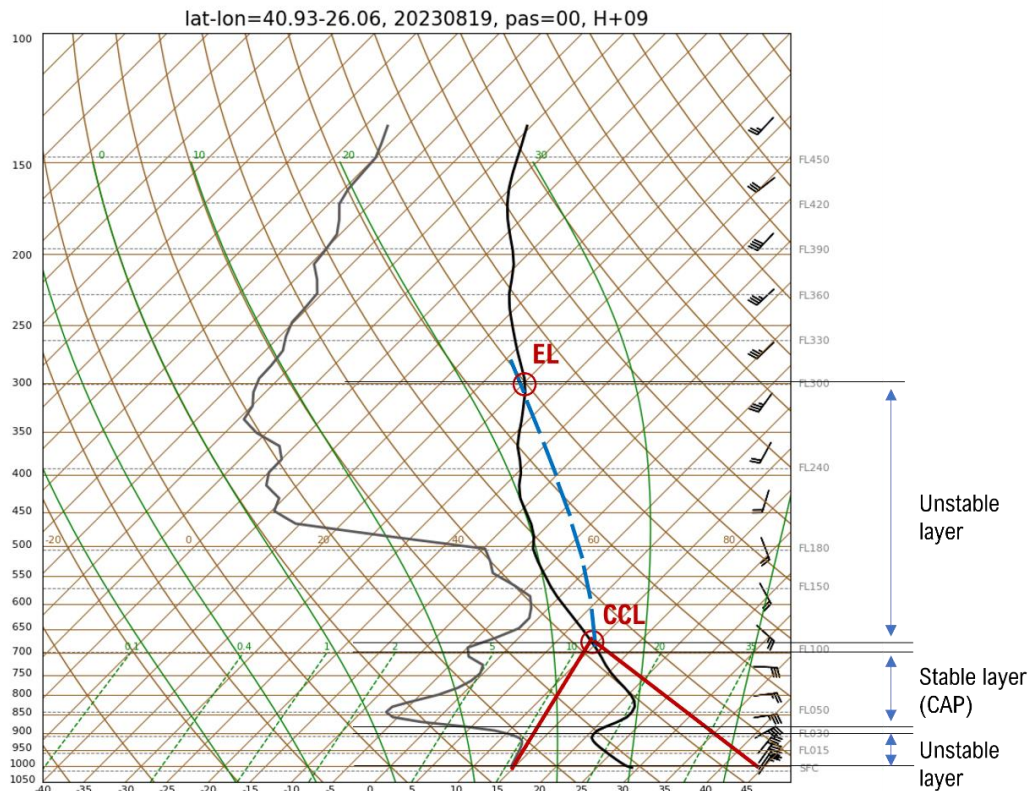


Figure 21 ECMWF model sounding for 19/08/2023 at 09:00 UTC (12:00 local time).

Around **14:00h** at local time, two almost simultaneous jumps of the highway to the south take place and generate a very high intensity race that reaches the village of Aetochori in about 1 hour, moving at more than 4 km/h and following the main NE wind direction. In about 4 hours the fire expanded from an area of 230 ha to 1,950 ha, affecting almost simultaneously two urban areas, the highway and a local road.

Table 4 Weather conditions forecasted at 19/08/2023 at 11:00 UTC, 14:00h local time by the ECMWF model.

Wind speed:	35 km/h (gusts up to 50-60 km/h)
Wind direction:	NE
Temperature (2m):	35°C (approx.)
RH:	22% (approx.)



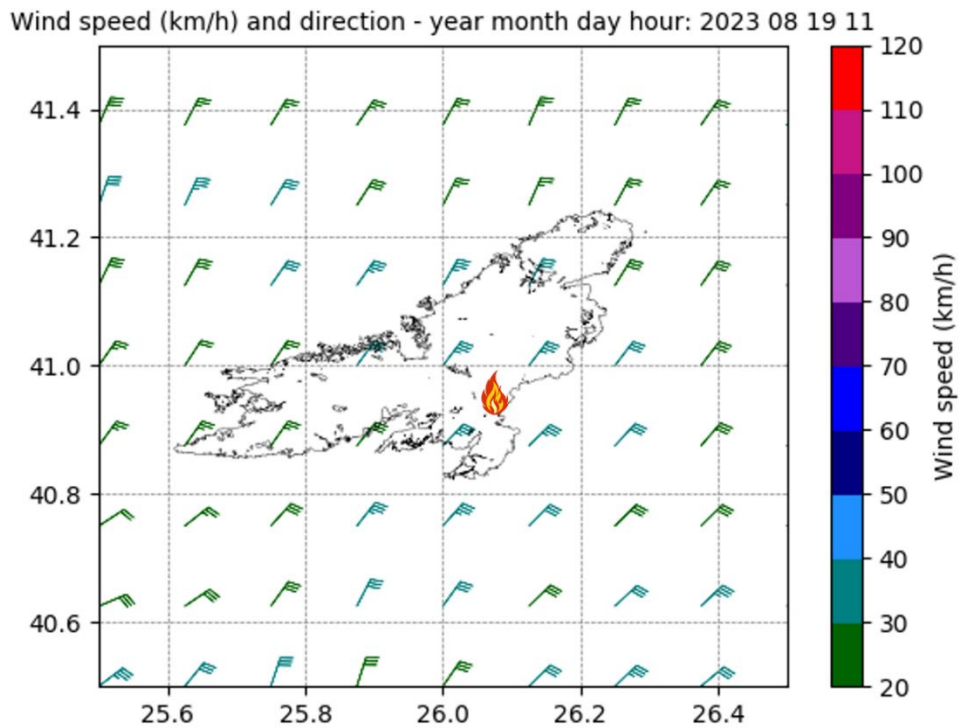


Figure 22 Wind conditions from ECMWF model for 19/08/2023 at 11:00 UTC (14:00 local time).

The Alexandroupolis Airport weather data shows that the wind at **11:00 UTC** was NE (37 km/h), again in good correlation with the ECMWF model.

Instability at the lower layer is at its peak for the day as the ECMWF sounding shows. Even though the main driver of the fire is the wind, and the plume is tilted, the instability in the boundary layer allows the plume to develop potentially up to 2.000 m in height. This change in the lower part of the atmosphere, together with temperature and RH values at this moment, explain the rapid development of the fire from 14:00h (local time). Pyrocumulus activity was very unlikely due to the strong cap preventing the smoke plume from reaching the CCL, but indraft winds inside the smoke column were strong enough to increase the rate of spread, fire intensity and the spotting activity, surprising the firefighters.

The next image shows the smoke plume developing vertically due to the instability in the lower layer of the atmosphere.





Figure 23 Video capture at 19/08/2023 at 18:40h (local time). Source: Hellenic Fire Service.



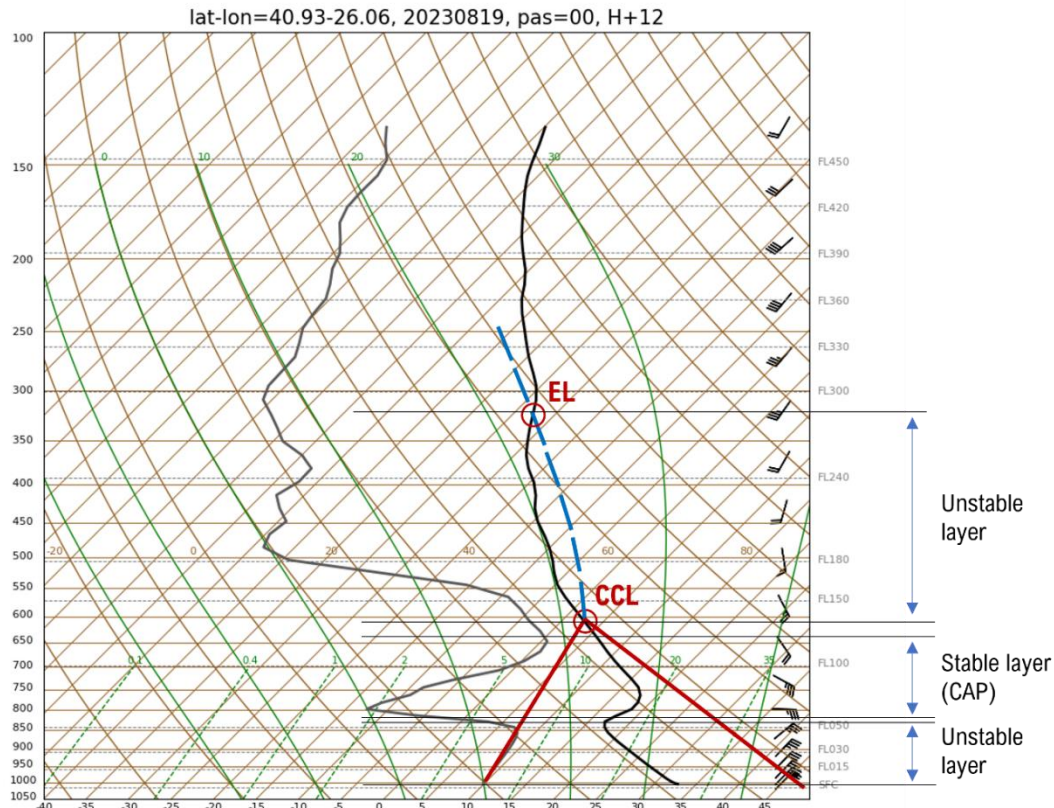


Figure 24 ECMWF model sounding for 19/08/2023 at 12:00 UTC (15:00 local time).

Before nightfall (at **20:15h local time**) the flanks had continued to grow, generating new head runs in SW direction that extended the perimeter up to 3.250 ha, threatening the towns of Doriko, Nipsa and Loutros.

As the afternoon hours passed, the instability in the lower layers decreased progressively, and during the night the fire propagated within stable atmospheric conditions, much less favourable for the fire to build intensity. The main driver for the fire during the night was the wind, which remained at speeds between 15-30 km/h on average, with occasional gusts around 50 km/h.

August 20th

Under similar weather conditions to the previous day, the fire replicated its spread pattern, opening the left flank to the East of Loutros by upwind, and with direct wind in the area of the villages of Amfitriti and Agnantia.



The efforts of the firefighting system are once again concentrated on the protection of vulnerable elements and on the reduction of the spread towards the city of Alexandroupolis.

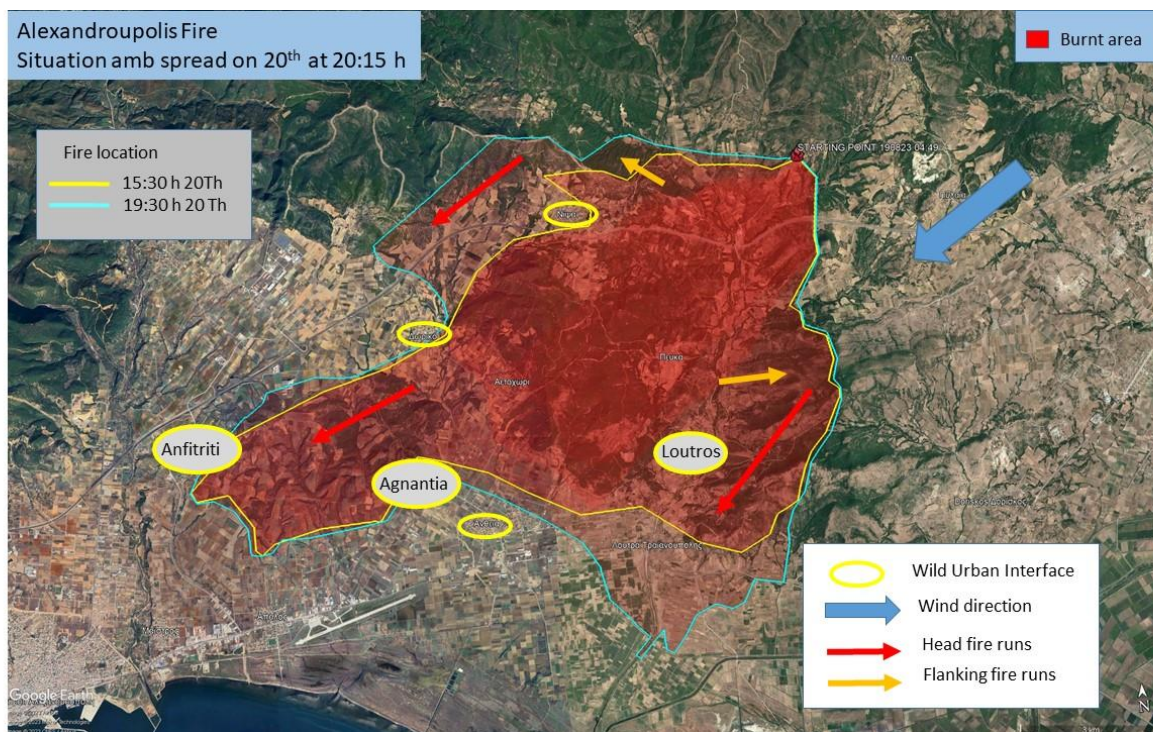


Figure 25 Evolution of the fire throughout the 20th with perimeter isochrones at 15:30 h and 19:30 h.

Average wind speed was around 30-35 km/h (NE), with gusts at the 50-60 km/h range. Maximum temperature was approximately 35-36°C, with minimum RH close to 22%. Atmospheric structure was very similar to that of the previous day. Peak instability in the lower layer at 14:00-15:00h (local time), which allowed the plume to develop potentially up to 2.000 m, capped with the same stable layer above. Fire behaviour was equivalent to that of the previous day, both during daytime and at night.



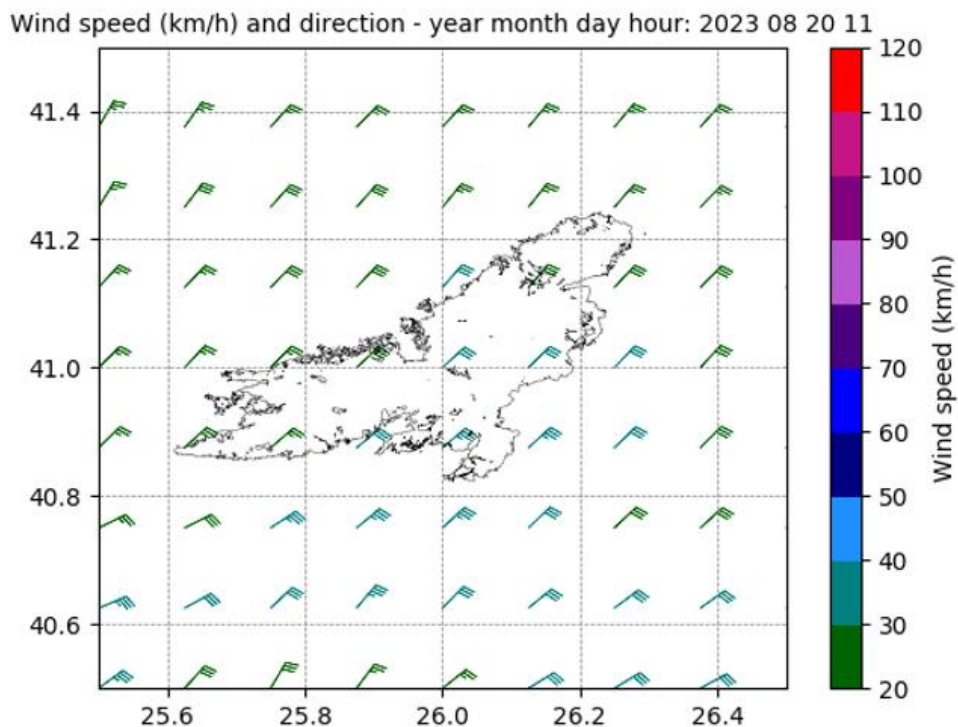


Figure 26 Wind conditions from ECMWF model for 20/08/2023 at 11:00 UTC (14:00 local time).



Figure 27 Video capture from 20/08/2023 at 15:37h (local time). Smoke plume influenced by strong winds coupled with instability in the lower layer of the atmosphere. Source: Hellenic Fire Service.

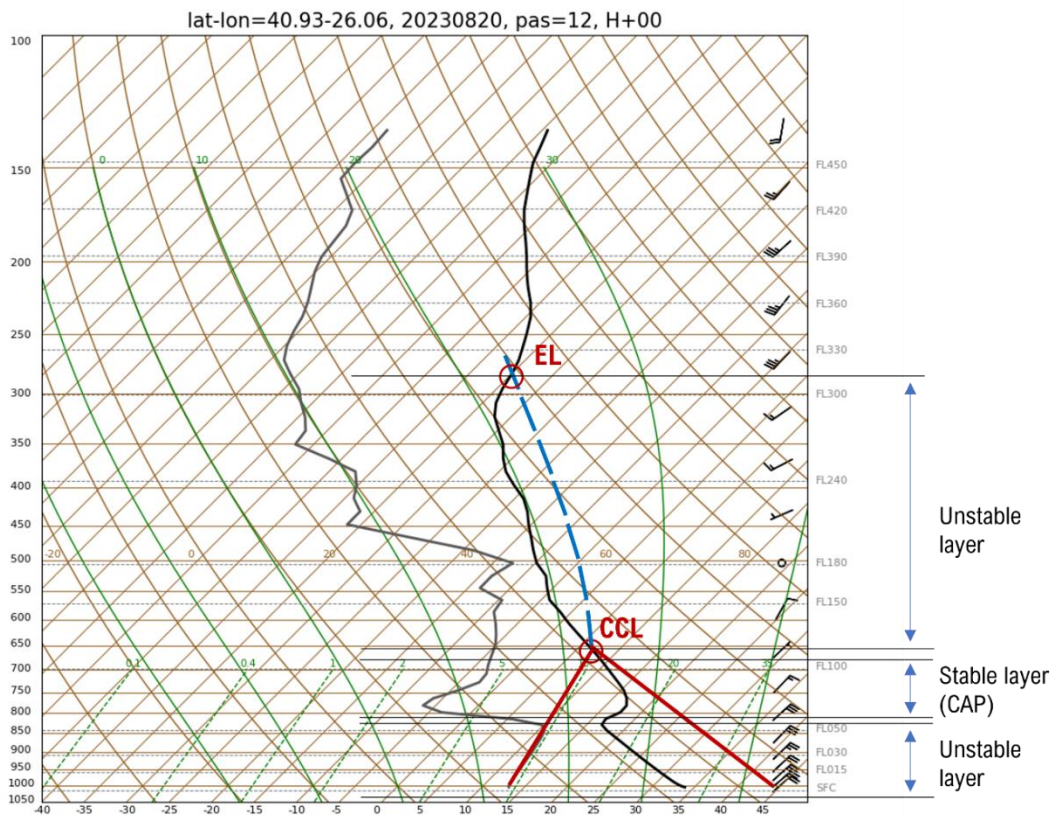


Figure 28 ECMWF model sounding for 20/08/2023 at 12:00 UTC (15:00 local time).

At the end of the afternoon, the fire was able to open the right flank to the west of Nipsa and to position itself in the mountain range that gives access to the interior of the main forest massif.

August 21st

Until the start of the Dadia-Soufli fire at about 13:05h, the Alexandroupolis fire presents a stabilised head and continues its evolution with a left flank opening towards the East but with a more limited projection than in the previous days because neither the orographic position nor the wind direction facilitates its development beyond the nuclei of Dorisco and Monastiraki.



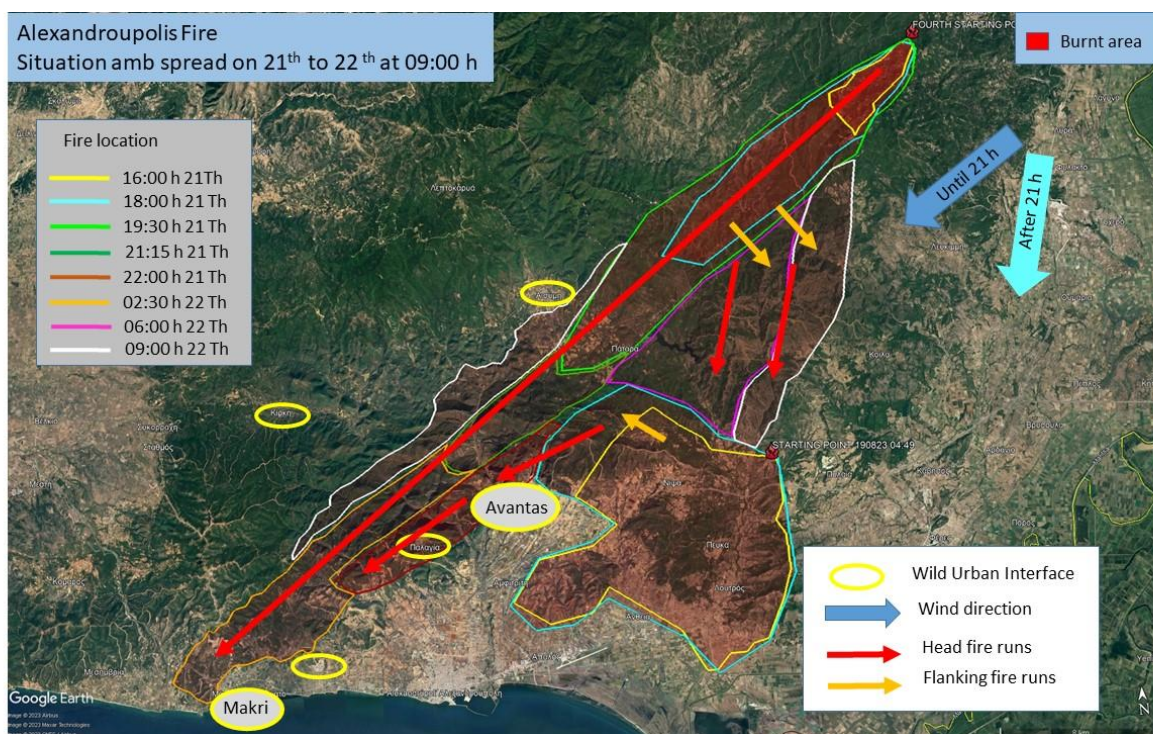


Figure 29 Evolution of the fire throughout the 21st and early morning of 22nd with perimeter isochrons.

The right flank, on the contrary, continues to be positioned in the mountain range located to the north between Avantas and Nipsa, replicating the same pattern of movement as the previous day with projections of the head towards the cultivated area between the two mentioned populations.

The start of the Dadia-Soufli fire shows a very intense behaviour from the first moment, with an axis of propagation marked by the wind direction and the ridge line connecting the starting point and the Lefkimi antenna complex. In less than 2 hours the fire has developed a pyrocumulus that will dominate the fire propagation pattern for the next 11 hours until the impact on the sea around Makri.

Table 5 Weather conditions at the time of the start of the Dadia-Soufli fire by the ECMWF model.

Wind speed:	35-37 km/h (gusts up to 45 km/h)
Wind direction:	NE
Temperature (2m):	36°C (approx.)
RH:	13-16% (approx.)



Table 6 Weather conditions from GFS model for 21/08/2023 at 09:00 and 12:00 UTC (12:00 and 15:00 h local time), at the start location of Dadia-Soufli fire.

Location: 41.09°N 026.16°E Reference date: NOAA-GFS: Mon 2023-08-21 06:00 UTC		Location: 41.06°N 026.11°E Reference date: NOAA-GFS: Mon 2023-08-21 12:00 UTC	
Wind (10 m)	51 ° 34.7 km/h 5 Bf	Wind (10 m)	57 ° 37.3 km/h 5 Bf
Wind gust	45.4 km/h	Wind gust	44.4 km/h
Cloud cover	0.0 %	Cloud cover	0.1 %
Precipitation	0.00 mm/h	Precipitation	
Temperature (2 m)	35.3°C	Temperature (2 m)	36.6°C
Relative humidity (2 m)	16 %	Relative humidity (2 m)	13 %

Alexandroupolis Airport weather station was recording winds from the NE, with average speeds of 39 km/h and up to 57 km/h gusts.

Ambient moisture was therefore much lower than previous days, with more potential to dry up both dead and live fuels. Atmospheric structure was also much more dangerous. The boundary layer was deeper and more unstable. At the same time, the capping layer was thinner and weaker. This means that the smoke plume had more potential to develop vertically (up to more than 3.000m) and was more likely to break through the capping layer, thus accessing the level of free convection above.



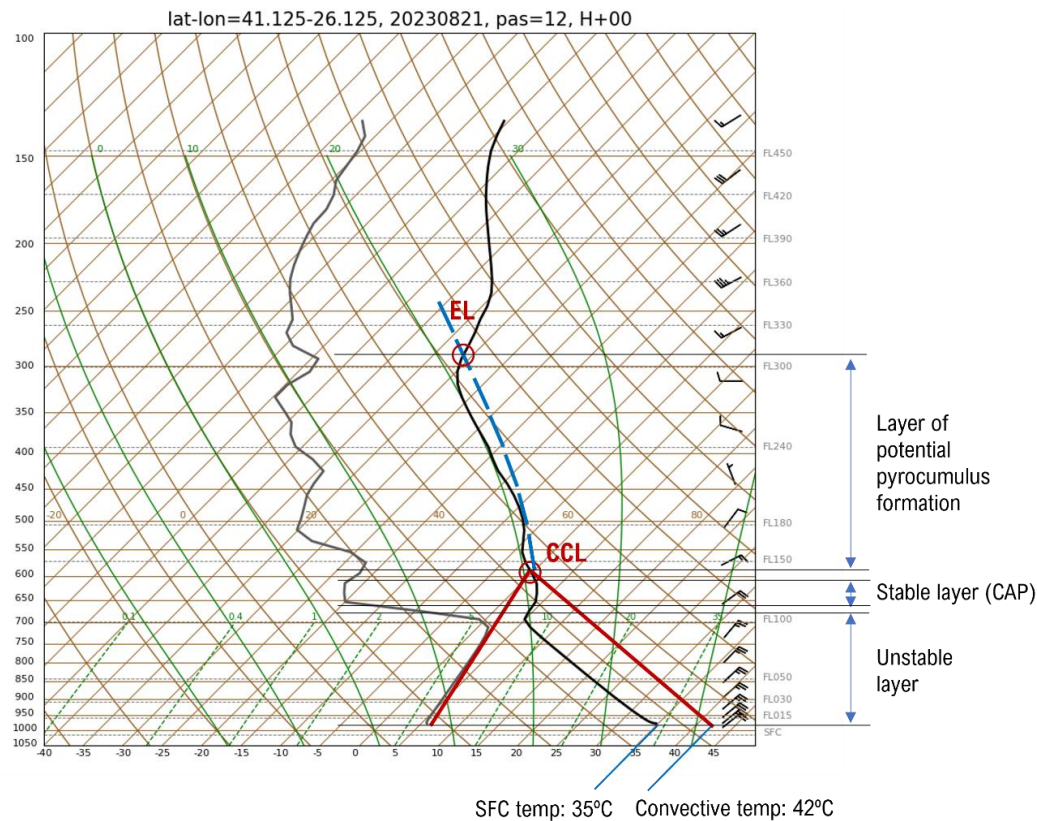


Figure 30 ECMWF model sounding for 21/08/2023 at 12:00 UTC (15:00 local time).

The combination of all these factors allowed fire behaviour during the 21st to be very intense and to have higher rates of spread. Regarding the Dadia-Soufli fire, the starting area and the continuity of fuels were also determining factors in its spread.

The effect of meteorological factors on fire behaviour is believed to have been the following: the Dadia-Soufli fire was already very aggressive from the beginning due to the wind speed, temperature, and relative humidity conditions in the area where it started. Although the intense winds tended to tilt the smoke plume, the strong instability in the lower layer together with the amount of heat released by combustion allowed the plume to develop vertically, adding a convective component to wind driven fire. The intensity of the combustion was enough for the heat island created by the fire to reach the convective temperature (42°C according to the ECMWF sounding). This temperature was the minimum required for the plume to reach the CCL, which marks the base of the pyrocumulus clouds that developed. The gap between convective and surface temperature was approximately 6-7°C, well within the threshold of what is possible for a fire that is burning such an amount of fuel load simultaneously.



The moment the plume was able to pass through the stable layer and reach the CCL, pyrocumulus clouds started to form, increasing the height of the column. Updraft currents within the plume got stronger, forcing indraft winds at the base of the flames, increasing effective wind speed, fire intensity, rate of spread and fire spotting events. All of this contributed to a feedback loop that sustained the fire's severe behaviour for the next several hours. .

The following image shows the smoke plume of the Dadia-Soufli fire vertically developing and being topped by pyrocumulus clouds.



Figure 31 Video capture from 21/08/2023 at 14:58h (local time Source: Hellenic Fire Service.

The following images show pyro convective activity produced by the smoke plumes.

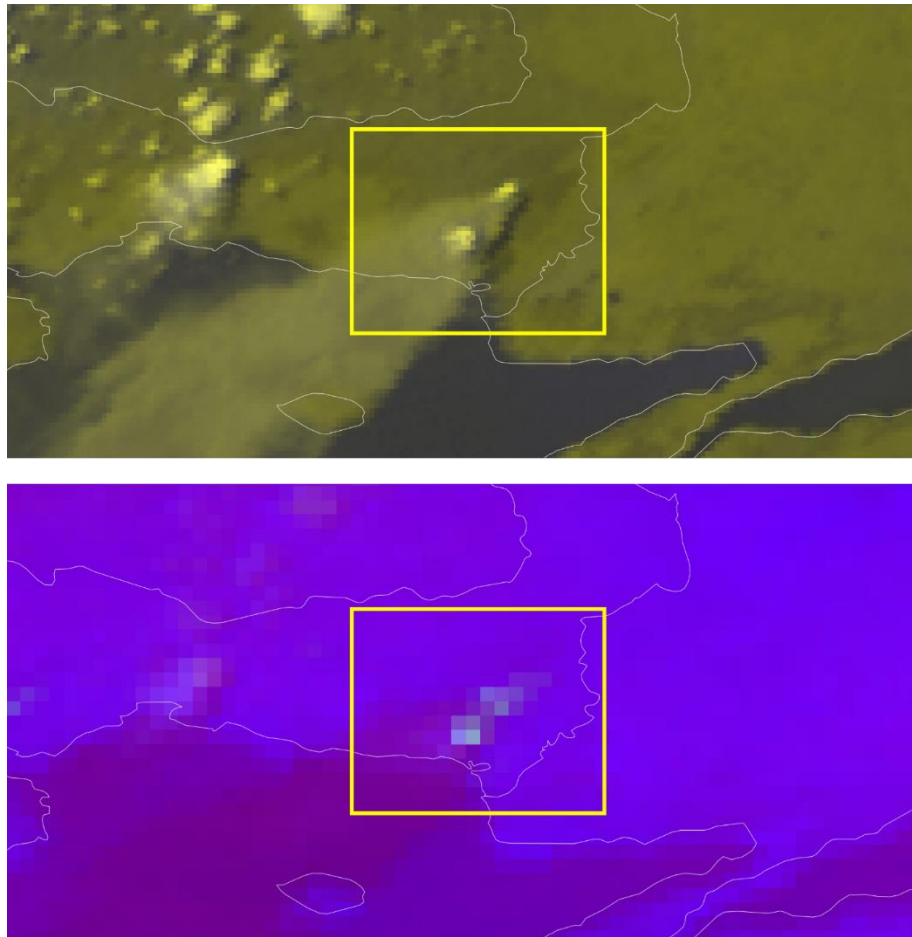


Figure 32 European HVR RGB composite from the SEVIRI instrument (upper image), and Convection RGB composite from MSG-0 degree (bottom image), at 21/08/2023 14:00 UTC. Source: EUMETSAT.

The updraft currents within the plume were so strong that they sucked the flanks inward, allowing for a narrow head run that propagated in a straight line to the SW, totally aligned with the direction of the wind.

The following image shows the Dadia-Soufli right flank smoke being sucked into the main plume due to the updraft currents.





Figure 33 Video capture from 21/08/2023 at 19:17h (local time). Source: Hellenic Fire Service.

At the same time, plume dynamics also involving the downdraft currents created turbulence at the head of the fire. This, together with the spotting fires ahead interacting with the fire front, created a dynamic in which the main run of the fire was not even reading the topography of the terrain. Rate of spread was therefore quite constant for hours.

This image shows turbulence and downdraft currents at the head of the Dadia-Soufli fire.



Figure 34 Video capture from 21/08/2023 at 18:42h (local time). Source: Hellenic Fire Service.

The development of the Dadia-Soufli fire starts to have an effect on the rate of spread of the opening of the right flank of the Alexandroupolis fire from about 16:00h onwards, due to the atmospheric depression generated in the space between the two fires, produced by the development of the pyrocumulus of the Dadia-Soufli fire.

In the foreground, right flank of the Alexandroupolis fire and the column of the Dadia-Soufli fire covering it all. The interaction of both columns accelerates the spread of the flank.



Figure 35 In the foreground right flank of the Alexandroupolis fire and the column of the Soufli fire covering it all. The interaction of both columns accelerates the spread of the flank.

It is estimated that both fires developed parallel head runs with a very marked direction towards the Southwest, jumping the road that joins Avantas and Aisymi with a lag of between 30 minutes and 1 hour, around 20:30h (local time).

The two fires merged just past the mentioned road and taken both fires as one, the projection continues its main axis affecting different inhabited areas such as Palagia and the University Hospital of Alexandroupolis.

From about 21:00h the general wind begins to turn NNE and the left flank section between the back and the Nipsas reservoir begins to open to the south with a speed and intensity similar to that of the main front. This is a series of consecutive runs impacting the first third of the right flank of the Alexandroupolis fire. The projection of the overture of the left flank of the Soufli fire encompasses the area affected by the Alexandroupolis fire on the 19th and 20th, and had the latter not occurred, the area burned on the 19th and 20th would have been affected by at least 70%.

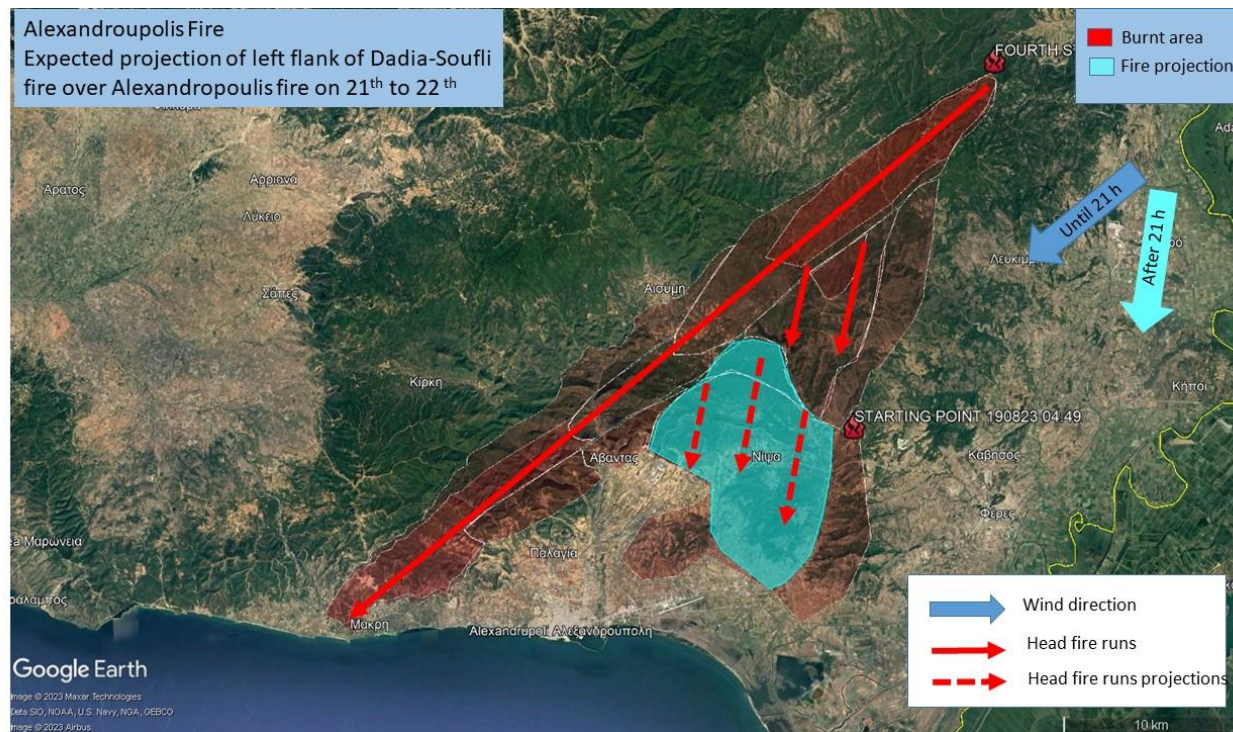


Figure 36 Expected projection of the left flank of Dadia-Soufli fire over Alexandroupolis

It should be noted that although the wind shift is general, the axis of propagation of the head of the fire is not altered. This fact is explained by the high energy developed by the pyrocumulus that governs the propagation of the head, which is able to cancel the effect of general wind shift that is occurring. On the other hand, the gradual decrease in temperature and wind intensity throughout the afternoon and early morning, as well as the recovery of relative humidity by almost 25% around the fire, does not present appreciable changes in the behaviour of the fire, neither in speed nor intensity.

The general structure of the atmosphere changed progressively during the afternoon and into the night, decreasing instability in the lower layers. From 21:00h (local time), the ECMWF model predicted the formation of a thermal inversion on the surface, which represents a situation of high stability that, under normal circumstances, usually helps to significantly reduce the intensity of the fire. ECMWF atmospheric sounding for the 21st at 21:00 UTC (00:00h local time) shows the thermal inversion at the surface, and a 17°C gap between the surface temperature and the convective temperature. This is a very marked difference and generally insurmountable for a fire under normal conditions.



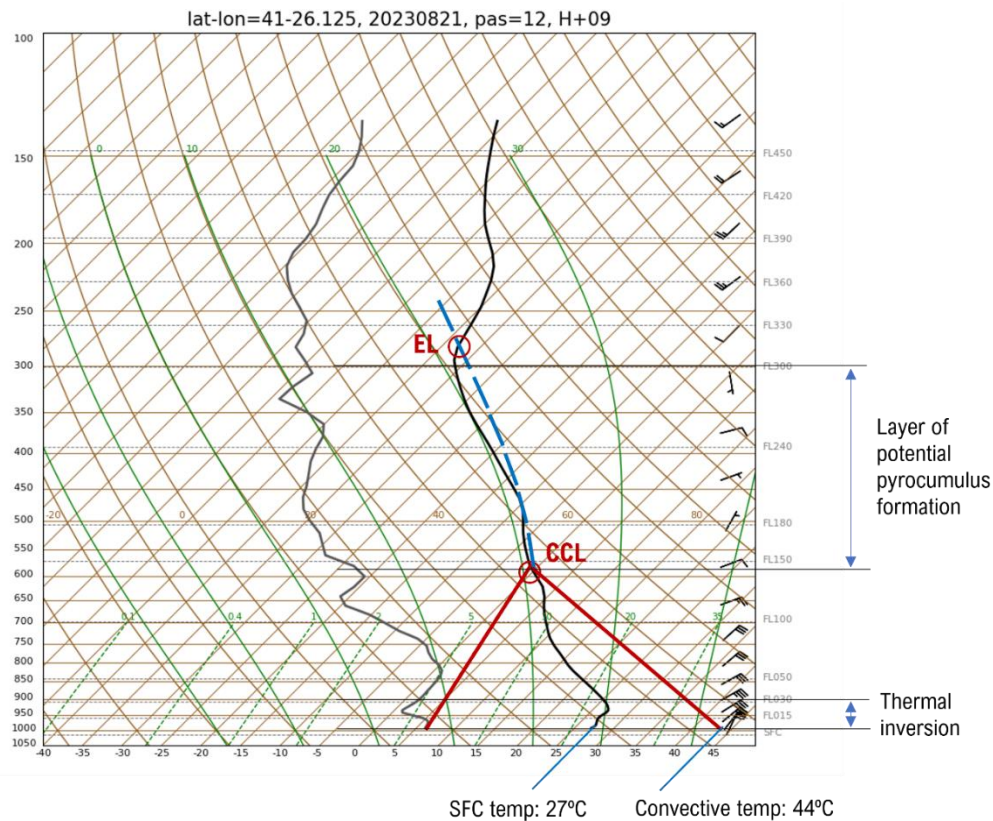


Figure 37 ECMWF model sounding for 21/08/2023 at 21:00 UTC (22/08/2023 at 00:00h local time).

However, the expected change for the better in fire behaviour did not take place during that night. According to our hypothesis, this was due to several factors:

- Under normal circumstances, the change in the atmospheric structure during the transition from afternoon to night time would have inhibited the convection processes as stated above. But the amount of thermal energy released from combustion processes during the day was so massive, that it managed to keep the capping layer open locally in the area of influence of the fire, maintaining the connection between the fire plume and the free convection level. In this way, the pyro convective processes continued during the first hours of the night, both at the head and at the left flank of the Dadia-Soufli fire, as can be seen in the satellite images. In other words, the fire created its own particular environment regardless of the general atmospheric conditions. That is, the amount of heat released during the combustion of fuels was so huge and in such a short period of time that heat dissipation processes were hampered. Temperature values in the area of influence of the fire remained high even though general atmospheric conditions changed. In this way, the area of influence of the fire was not affected by the thermal inversion. Conditions remained favourable for fire propagation and, at the same



time, the gap between the surface temperature and the convective temperature was very similar to the one existing during daytime, allowing the smoke plume to keep exhibiting convective behaviour and pyrocumulus development. This scenario was unique for this particular night due to the amount of thermal energy released, and it couldn't be replicated on subsequent nights.

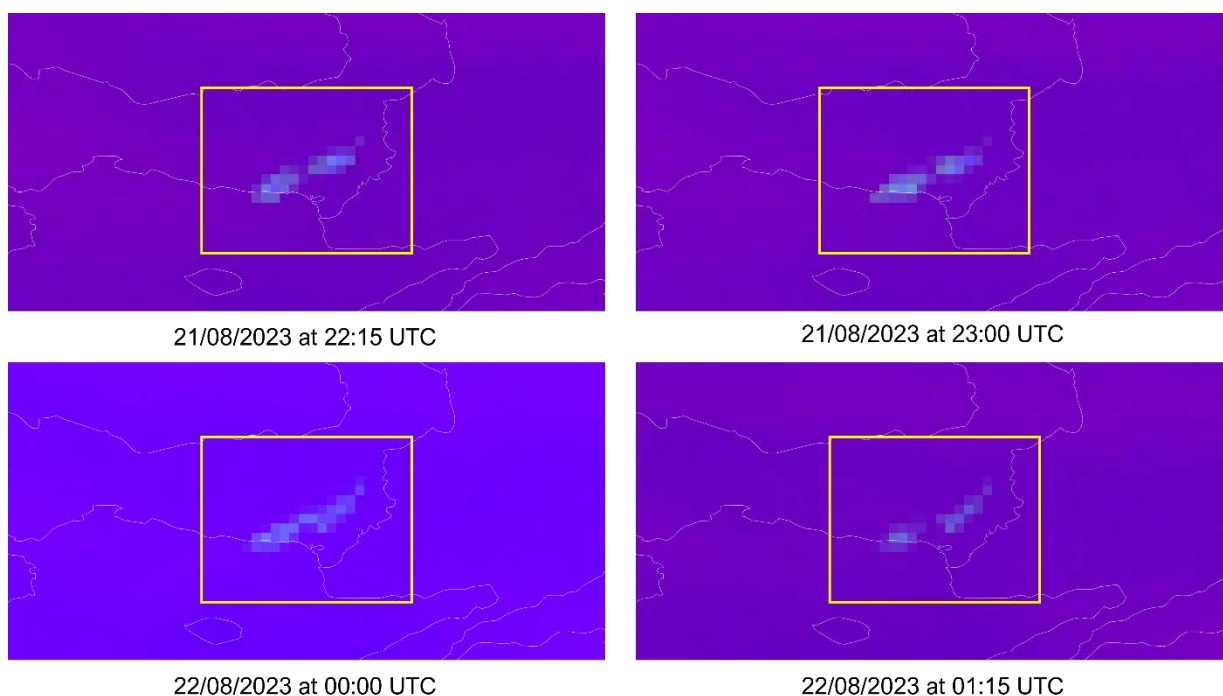


Figure 38 Pyro Convective activity during the night of the 21st to 22nd of August. Convection RGB composite from MSG-0 degree. Source: EUMETSAT.

In addition to this, the wind direction changed to N-NE components at the beginning of the night, facilitating the opening of the left flank of the Dadia-Soufli fire. This active fire front was very long, and it burned approximately 7.500 ha during the night (at a rate of almost 1.000 ha/h), contributing to the large quantities of thermal energy released to the atmosphere.



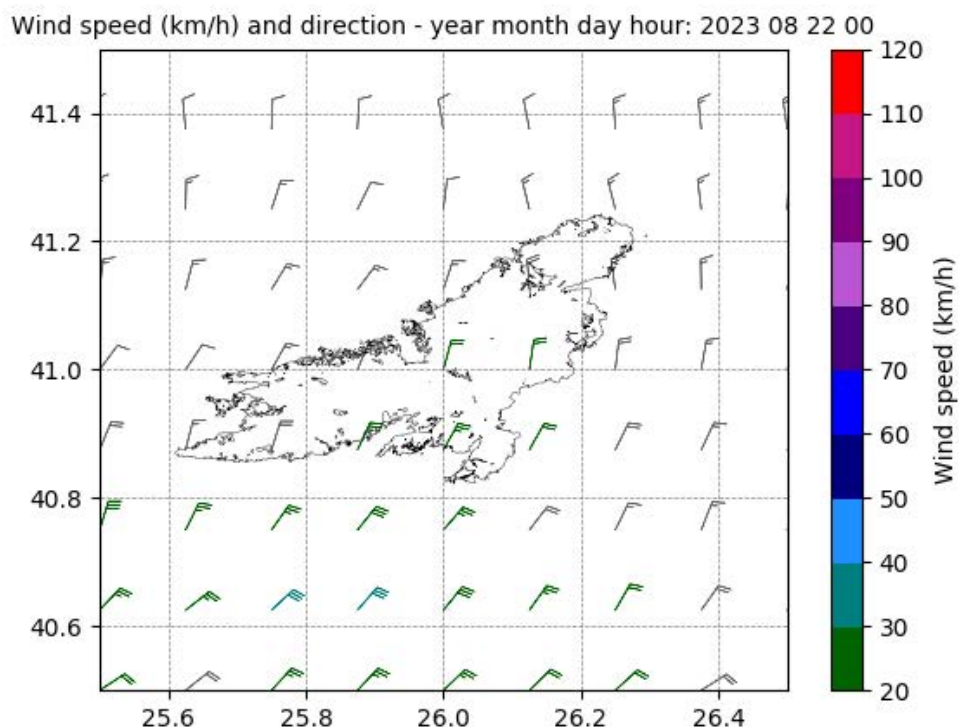


Figure 39 Wind conditions from ECMWF model for 22/08/2023 at 00:00 UTC (03:00 local time). Wind direction had changed from NE to N components during night time.

The final result is a linear run of about 50 km in length produced by the Soufli fire, which maintains a fairly uniform course and speed of about 4 km/h throughout the 13 hours it takes to impact with the sea. The surface growth in this period is about 30.000 ha with an hourly growth rate of 2.300 ha/h. If the projection of the overture of the left flank of the Soufli fire is taken into consideration on the area already burned by the Alexandroupolis fire on the 19th and 20th, the surface reached would have been 36.000 ha and an hourly growth rate close to 2.800 ha/h.



August 22nd to 24th

Within this period the NE wind component remains more or less constant with fluctuations in intensity. The right flank is established as the main driver of the major reproductions with less activity on the left flank. The reproductions generate important head runs with convective behaviour that do not reach the growth rates of the afternoon of August 21st, possibly because they access areas with less fuel or burnt the previous days.

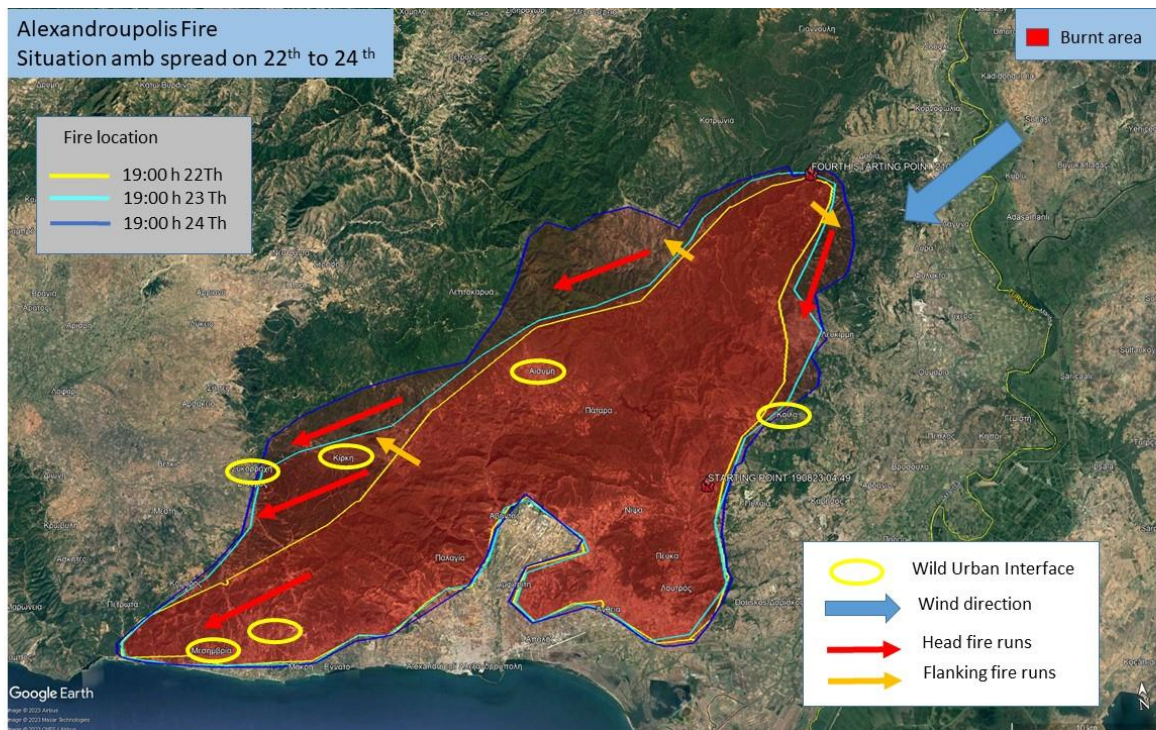


Figure 40 Evolution of the fire throughout August 22nd to 24th with perimeter isochrones at 19:00 h.

Table 7 Weather conditions forecasted at 22/08/2023 at 12:00 UTC, 15:00 local time by the ECMWF model.

Wind speed:	25 km/h (gusts up to 45-55 km/h)
Wind direction:	E-NE
Temperature (2m):	36°C (approx.)
RH:	17% (approx.)



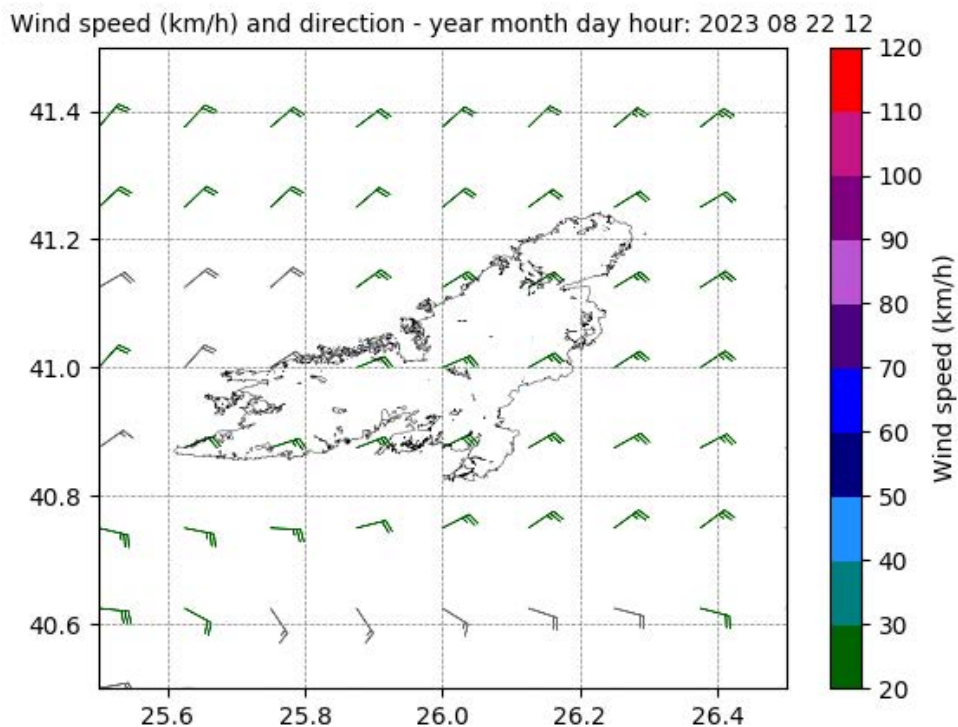


Figure 41 Wind conditions from ECMWF model for 22/08/2023 at 12:00 UTC (15:00 local time).

The Alexandroupolis Airport weather data shows that the wind at 12:00 UTC (15:00h local time) on the 22nd was E-NE (37 km/h, with 56 km/h gusts), a bit higher than what the model forecasted.

The ECMWF model sounding for the 22/08/2023 at 12:00 UTC (15:00h local time) shows again potential for pyrocumulus development. The boundary layer was deep and unstable, and the capping layer was weak. The difference between surface temperature and convective temperature was again approximately 7°C, and once the fire developed intense runs the smoke plume was able to reach the Convective Condensation Level (CCL) and form some pyrocumulus clouds, most of all along the right flank, which had a considerable opening towards the W. Fire behaviour was thus very intense and aggressive for most of the day, and convective activity carried on until approximately 22:00-22:30h (local time). During the night, stability conditions prevailed and inhibited convective behaviour.



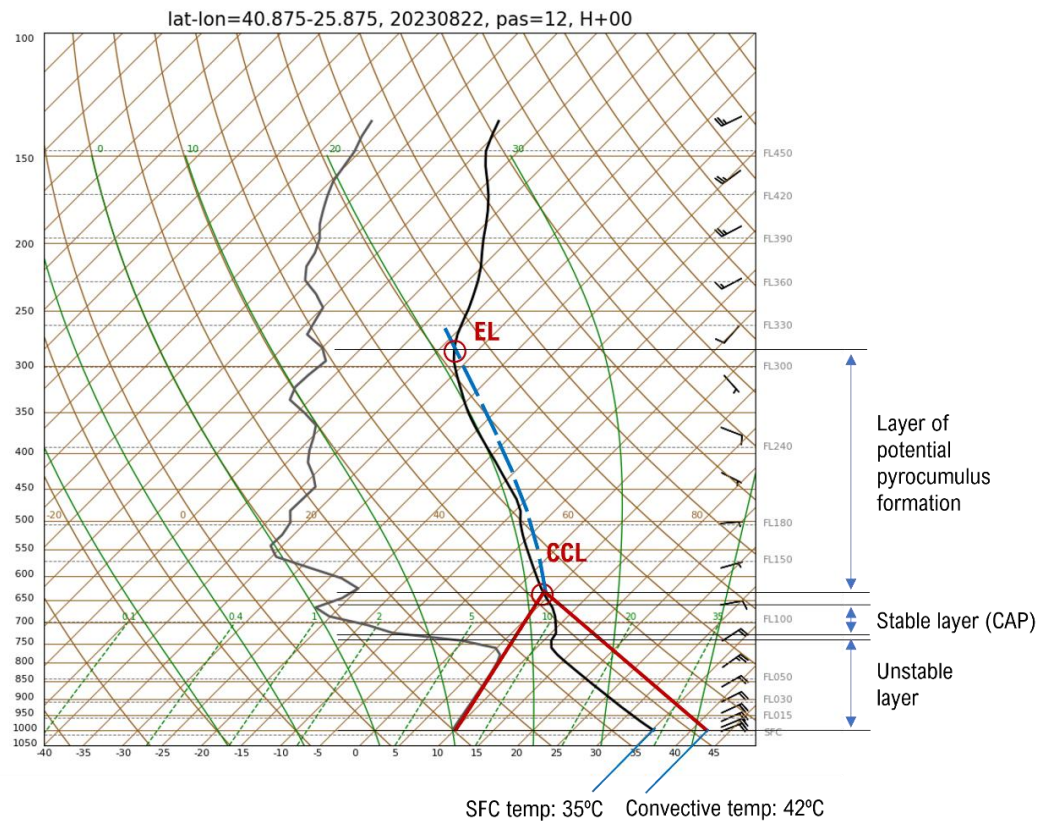


Figure 42 ECMWF model sounding for 22/08/2023 at 12:00 UTC (15:00 local time).

The following image shows a smoke plume strongly developed in height topped with a pyrocumulus cloud at the right flank of the fire, in full agreement with the atmospheric structure predicted by the ECMWF model.





Figure 43 Video capture from 22/08/2023 at 18:23h (local time). Source: Hellenic fire service.

The following image shows the pyro convective activity produced by the smoke plume mostly at the right flank.

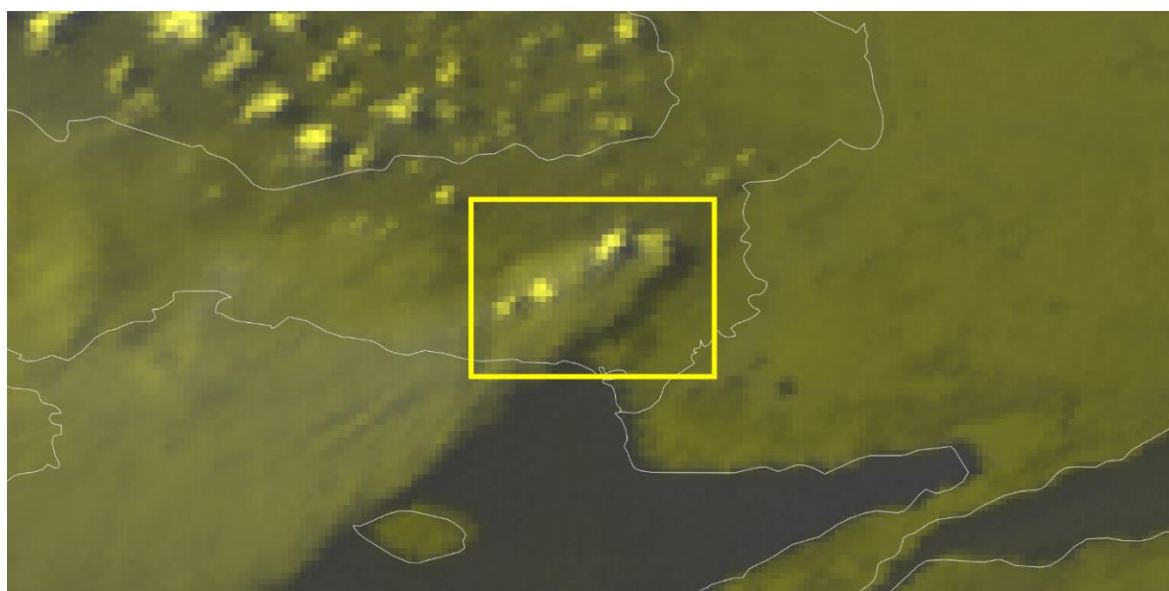


Figure 44 European HVR RGB composite from the SEVIRI instrument. 22/08/2023 at 14:45 UTC. Source: EUMETSAT.

Several villages, such as Aisymi, Plaka, Dikella, Atarni or Mesimvria, were again affected on the 22nd by the overture of the right flank, and others already in the early morning of the 22nd to the 23rd as Kirki or Sikorrachi.

During the 23rd and 24th weather parameters were much like the previous day. Unstable atmospheric conditions allowed the same plume dynamics and some intense runs exhibited pyrocumulus activity which can be seen in the next figure at the right flank of the fire, also in full agreement with ECMWF model sounding.



Figure 45 Video capture from 23/08/2023 at 14:59h (local time). Source: Hellenic Fire Service.

August 25th to September 3rd

Within this period, the fire continued to grow, but in a much more contained way, mainly on the right flank.

But, as it turned out, it is between August 29th and 31st when the most outstanding growth occurs with the general change of wind direction. This happened due to the passage of a front on the 29th from SW to NE over the fire area, which re-ignited the back of the fire. The sequence of satellite images shows the change in wind direction with this frontal passage, and the smoke plume that rose from the re-ignited area.

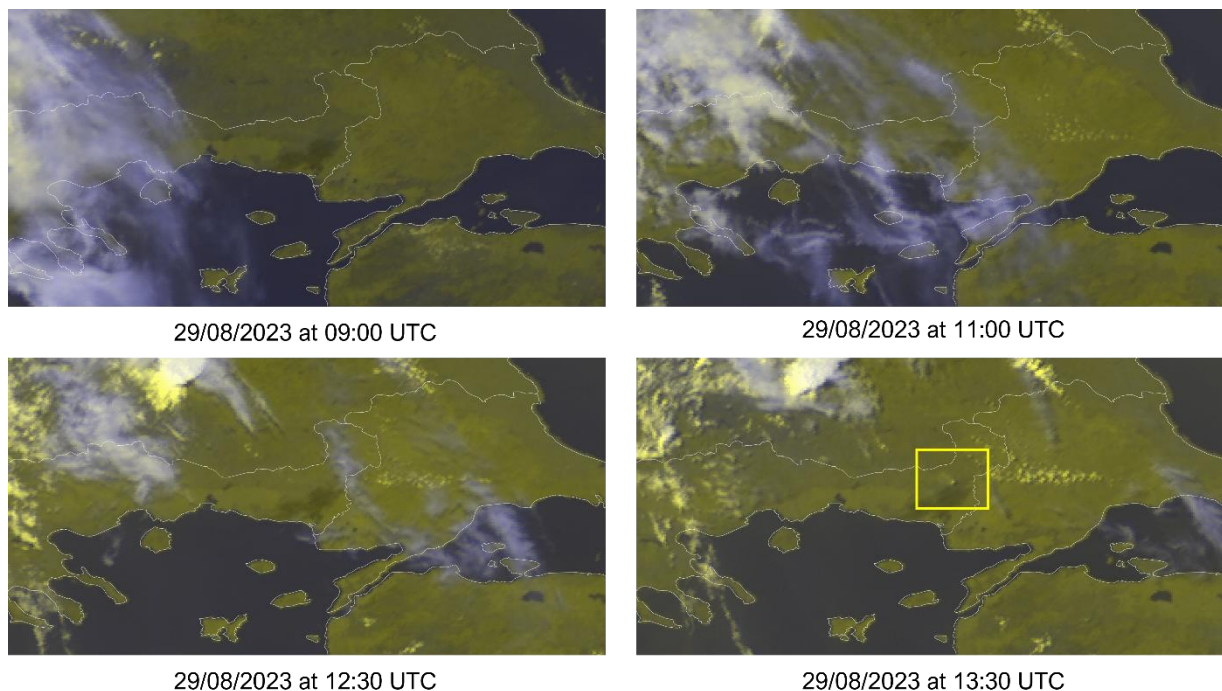


Figure 46 European HVR RGB composite from the SEVIRI instrument. Source: EUMETSAT.

This new spread of the back of the fire in a north-easterly direction had a magnitude of approximately 10.000 ha. The following sequence of satellite images shows the fire spreading to the Northeast with the change in wind direction. The smoke plume was exhibiting pyrocuulus activity during August 30th.



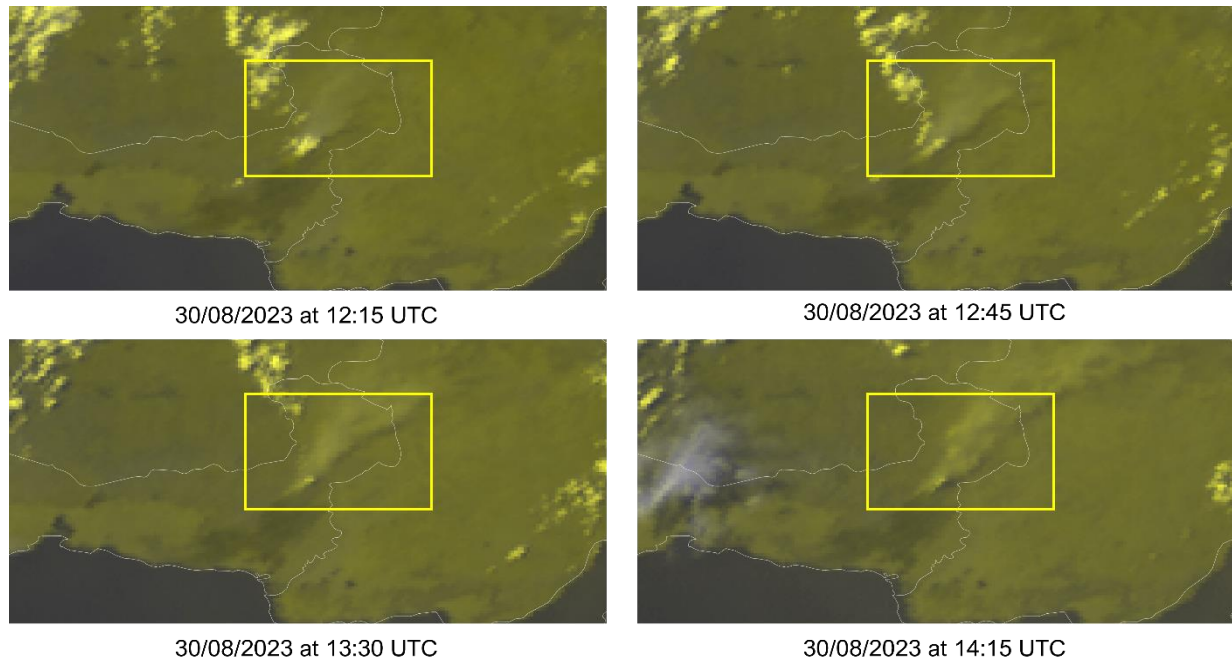


Figure 47 European HVR RGB composite from the SEVIRI instrument. Source: EUMETSAT.

The following map gives an overview of the isochrones of the development and the growth of burnt area and fire perimeter evolution as well as the final perimeter.



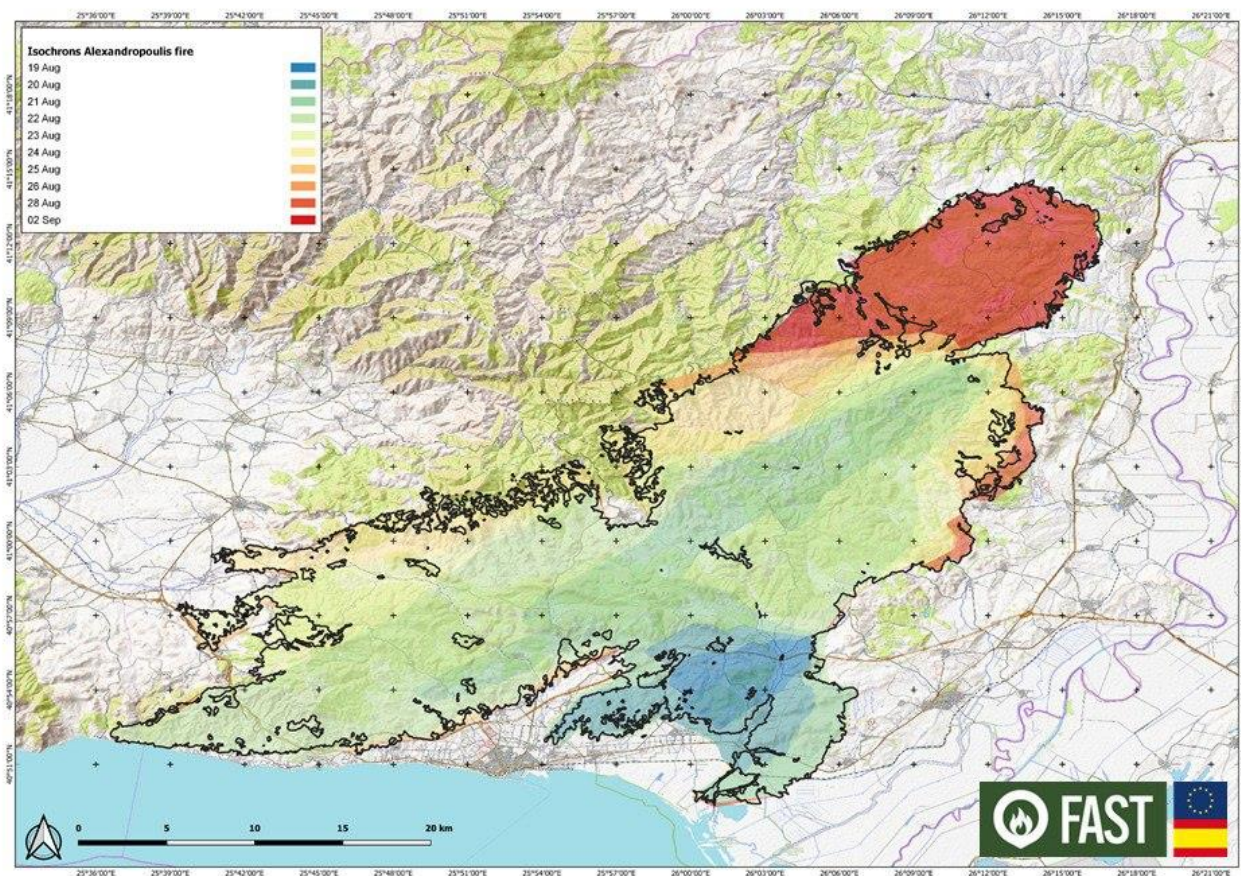


Figure 48 Isochrones and burned area growth from 19 August to 2 September. Processed by FAST team Greece-2023.

POST FIRE SITUATION

Post-fire severity analysis is crucial to assess the environmental damage caused by wildfires, plan ecosystem restoration, evaluate future risks, protect public health, facilitate scientific research, and make forest management decisions.

To assess the severity of the fire, two Sentinel 2 images were used, one pre-fire and one post-fire, as well as the perimeter estimated by the Copernicus Emergency Management Service (CEMS). The NBR (Normalised Burn Ratio) index was calculated for each image. This index uses the near infrared (NIR) and shortwave infrared (SWIR) bands to highlight burnt areas, according to the formula shown below. A high NBR value indicates healthy vegetation while a low value indicates bare ground and recently burnt areas. Non-burnt areas are normally attributed to values close to zero (Normalized Burn Ratio (NBR) | UN-SPIDER Knowledge Portal, n.d.).



$$NBR = \frac{NIR-SWIR}{NIR+SWIR}$$

Subsequently, the difference in indices between one image and another was calculated. Thus obtaining the dNBR, based on the values of which the levels for classifying fire severity are established, it reflects the intensity and the degree of vegetation damage: a higher value of dNBR indicates more severe damage, while areas with negative dNBR values may indicate regrowth following a fire.

The fire severity levels used are those proposed by Botella-Martínez and Fernández-Manso (Botella-Martínez & Fernández-Manso, 2017):

- Low severity: in the case of the tree canopy, the crowns have remained largely undisturbed and therefore remain almost entirely green. The shrub canopy shows signs of scorching, but burnt patches are not predominant.
- Moderate severity: in the tree canopy, more than half of the area covered by the crowns is scorched, but the leaves or needles are preserved, so the brown color predominates. The undergrowth is mostly charred, but the ash observed is predominantly black in color.
- High severity: in trees, the crowns are completely consumed in more than 50% of the area covered, with no leaves or needles or fine elements remaining, so the color black predominates. The undergrowth is completely charred, with only the thickest elements remaining. The ash has predominantly gray or whitish tones.



Figure 49 Different fire effects on the vegetation: moderate severity (left) and high severity (right) in Alexandroupolis.

After calculating the dNBR index, 60% of the area affected by the fire corresponds to high - very high severity, and almost 25% corresponds to moderate - high severity, less than 10% of the area has been classified as moderate-low severity (Figure 50).

Percentage of severity class

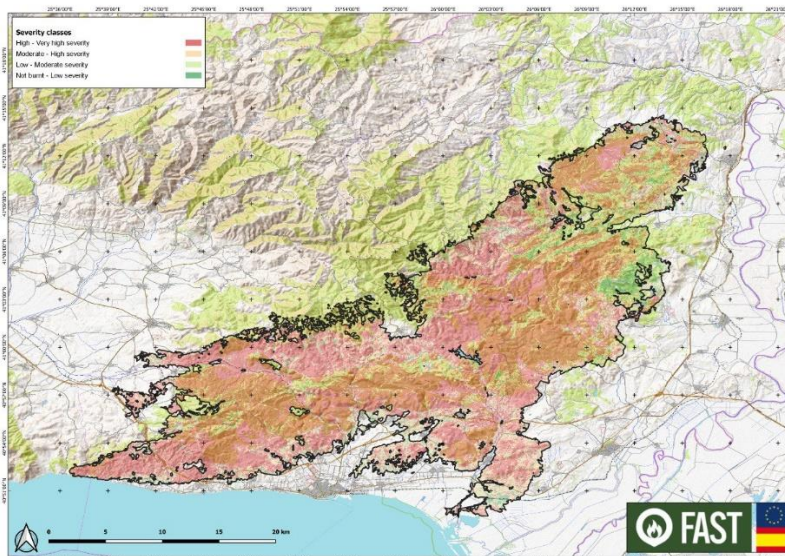
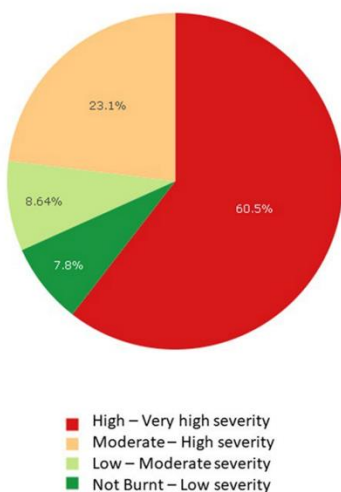


Figure 50 Percentage of severity classes in the fire and map of their distribution. Processed by FAST team Greece-2023.

The distribution of high severity corresponds to the main fire spreads, without differentiating species distribution or orographic features. In addition, canyons bottoms correspond to moderate or low severity, suggesting the intensity and high spread of the front, which passed in a straight line over the ridge axes, jumping at high speed over the canyons and burning them once it passed, with a lower intensity. The non-differentiation of species is more evident in the NE area of the fire, where mixed coniferous and broadleaved stand are predominant and where low or not burnt severity can be found. In this area the fire burned like back fire or flanking.

Only agricultural or grazed areas break this continuity. Managed areas have a lower fuel load, thus changing the fire behaviour. An example of this is the olive groves, where it can be observed that the canopies undermined but still with leaves present, while the adjacent areas present a high severity (no leaves in the tree canopy). We can also observe the difference in the soil: while in many olive groves the herbaceous structure has been preserved, in the surrounding areas the entire vegetation layer has been lost. Apart from atmospheric characteristics, fuel load, continuity, and availability are key factors explaining fire behaviour in general, and particularly during the events analysed in this report, especially during the 21st. Without these ingredients, fire could not have sustained such intense runs and would not have been able to create its own environment. Fuel



availability (moisture content) cannot be modified on a large scale, but forest managers can act on the fuel load and continuity at the landscape level. It is not just a matter of silvicultural treatments, which are very expensive over large areas. It is a matter of returning to a mosaic model of landscape management, integrating extensive agricultural and livestock activities, and forestry uses in those places that are suitable for them.



Figure 51 Cultivated areas break the fuel continuity structure, modifying fire behaviour and decreasing fire severity.

Preserving the vegetation layer (low severity) is of paramount importance in preventing soil erosion. Plant roots serve as steadfast anchors, firmly securing the soil in place and safeguarding it from being washed away by rainwater (Andreu et al., 2001; Cerdà & Rodrigo-Comino, 2020). Furthermore, the vegetation acts as a robust shield against the erosive impact of raindrops, significantly diminishing the risk of splashing-induced erosion. Over time, splash erosion can erode away the precious topsoil layers, washing away vital nutrients and organic matter essential for sustaining plant growth. This depletion can impoverish the soil and hinder the ability of vegetation to regenerate within the affected area.

The consequences of soil erosion extend beyond the soil itself. It can lead to the sedimentation of nearby water bodies, such as streams and rivers. This sedimentation can have detrimental effects on water quality and the delicate balance of aquatic ecosystems, as the transported sediments often contain harmful chemicals that pose a threat to aquatic life.

Additionally, it's worth noting that the intense heat generated by the fire in high severity areas can alter the soil's structure, rendering it more water-repellent. This alteration further elevates the risk of erosion, as water is less effectively absorbed, exacerbating the potential for runoff and soil loss.



On the other hand, low-load areas provide a buffer zone that make it possible to mitigate the impact of the fire on the urban centers. A clear example can be found in Plaka, where a livestock herd keeps the surroundings of the village practically free of scrub.



Figure 52 Presence of a pastoral area on the upper edge of the village of Plaka served to mitigate the impact of the fire

FINDINGS

The following findings are based on the knowledge and experience of the FAST experts, the analysis of all information used for this report and the observations during the field visit in Alexandroupolis and Dadia-Soufli forest fires:

- No significant difference in fire behaviour has been found regarding vegetation species. Oak stands burned with the same intensity and severity as pine stands. This is a demonstration that what is fundamental is the structure, continuity and availability of the fuel (i.e. the fuel model), and not the species. For this reason, no cause-effect relationship was found between the main existing species and the observed virulent behaviour of the forest fire in the different areas of the fire.
- It has been confirmed that during the episode, the atmospheric dynamics have been very important to explain the observed fire behaviour. The increase in instability in the lower layers facilitated the development of convective behaviour that started on August 21st and was maintained during daylight hours for several days in a row. During the night hours, the change to stable situations and their prevalence inhibited pyroconvective behaviour, as is usually the case. However, on the night of August 21st to 22nd, the



convective behaviour continued for several hours, independently of the change in the atmospheric structure. This was because the fire managed to generate its own fire environment due to the enormous amount of heat energy released during its diurnal spread, as explained in detail in the fire reconstruction section.

- The behaviour of the fire that originated in Dadia-Soufli on the 21st was characterised by the convective activity that the smoke column developed, with spotting fires **jumping from 200 to 500 metres** and pulsations at the head with propagation speed ratios greater than **5-6 km/h**. The estimated average flame lengths at the head were over **40 metres** with **90,000 Kw/m** of front intensity. These fire behaviour values were outside the suppression capacity of any forest fire or emergency service. The relevant aspect about this case is that the fire was also capable of maintaining the same fire behaviour during the night, making it impossible to fulfil control manoeuvres that fire services can usually carry out with more favourable night conditions.
- However, in the analysis of the evolution of the fire, it was found that the forecasts of the European Centre for Medium-Range Weather Forecasts (ECMWF) were quite accurate and consistent throughout the episode, both in terms of surface variables and in the modelling of the atmospheric structure. Having this type of high-precision models is essential to reduce the level of uncertainty during wildfire management, and to be able to predict fire movements and anticipate when developing the strategy. However, it is necessary to have specialised personnel capable of translating all this data into operational information useful for decision making. The figure of the fire analyst or the analyst team is becoming a fundamental tool in the management of wildfire emergencies and are explained in detail in the "Guidelines of fire analyst competencies and skills" from AFAN. This person or team have a continuous vision of how the scenario is evolving, not only for days or hours, but also for months. Therefore, it is not a one-off analysis made on demand for a specific situation but a long-term continuous work (Castellnou et al., 2021).
- The collection of the meteorological data necessary for the reconstruction of the state of the atmosphere during the days when the forest fires were active has been very complicated due to the lack of meteorological stations belonging to the Hellenic Fire Service. It is highly recommended to devise a plan to install a network of weather stations in strategic places to provide accurate information. This kind of data is very important to check the reliability of weather forecasts and anticipate changes in fire behaviour, specially in cases where topographic interactions can modify general weather patterns unforeseen by numeric models. Also providing certain resources with small meteorological portable stations, so that they can take data and communicate them immediately, is very useful to this system, as they can collect data at complicated points such as perimeters, fire fronts, etc.



RECOMMENDATIONS AND GENERAL BEST PRACTICES

The following findings are based on the knowledge and experience of the FAST experts, the analysis of all information used for this report and the observations during the field visit in Alexandroupolis and Dadia-Soufli forest fires:

The order in which they are described does not denote any kind of priority or importance.

ACTIONS ON MANAGEMENT OF FUELS

It is recommended to:

- The existing network of firebreaks in the area of Dadia, Soufli and Alexandroupolis has not been able to contain the spread of the fire. It is a network designed to help contain surface fire fronts without spotting. It must be accepted that the behaviour of current and future wildfires will in most cases exceed the current firebreaks, and therefore it is proposed to redesign and adapt the strategy for planning firefighting infrastructures.
- It is proposed to implement an infrastructure planning to support the containment of large fires based on confinement axes, with area treatments sized to contain fires with a spotting capacity of 500 m at the head and lateral spots in flanks of 50 to 100 metres. These low fuel load areas can be supported in agricultural areas and must preserve forest structures that ensure a low or medium intensity fire behaviour (Arilla et al., 2020).
- Promote perimeter tilling of agricultural fields after grain harvesting to facilitate fire containment even in the case of spotting fire spread and to serve as anchor areas for suppression operations.
- Implement a plan to adapt the vegetation around houses and urbanised areas to reduce the risk of forest fires. The objective is to improve the self-protection of people and property and reduce the demand for firefighting resources for their protection. The suppression resources released can be used to limit the spread of the fire and thus prevent further damage to other vulnerable elements.
- Promote forest management that ensures the resilience of ecosystems and the reduction of the risk of spread in such high intensity, in the context of adaptation to climate change. The exposure of forest stands



to periods of deficit precipitation and an almost permanently higher average temperature range at any time of the year predisposes species to a very pronounced water stress. The result is a significant accumulation of biomass available for burning with the capacity to trigger very intense fires. Forest management should promote biomass reduction to regulate competition for water to reduce water stress, promoting forestry and extensive livestock use that integrates biodiversity preservation criteria (Life+ Cost-Efficient Integration of Megafire Prevention into Forest Management in the Mediterranean, n.d.).

- Use of prescribed burning as an ecosystem management tool, both for silvicultural purposes to reduce competition, improve pastures for livestock grazing, and for habitat conservation. This prescribed burning also represent a training opportunity for the response teams to implement safer and more efficient tactical fire management. Tactical fire is a key skill in order to face large high intensity fires (Beltrán, M. et al., 2018).

ACTIONS ON FOREST FIRE FIGHTING OPERATIONS

- Because the forest fire affects urban structures, urban-forest interfaces, motorways, conventional roads, power lines, communication towers, military bases, industrial estates, etc., this type of emergency becomes a multi-emergency. For this reason, the suppression resources must be prepared, equipped, and trained to deal with this type of situation. The Incident Commanders must be properly instructed in this type of situation to be able to manage all the resources in the most efficient way, and to be able to activate those resources that are not directly involved in suppressing forest fires to participate in the emergency. It is recommended to establish protocols and procedures for joint action between the different types of resources and administrations involved (unified command), and even other European governments or Greece's neighbours. In case these protocols and procedures already exist, different simulated situations should be trained in order to be able to detect the areas of the system that needs reinforcement, as well as to detect the strengths to make them more solid. (STRATEGIC GUIDELINES FOR FOR WILDLAND FIRE MANAGEMENT IN SPAIN, n.d.)
- The Alexandroupolis and Dadia-Soufli forest fires have shown the complex phenomenon of forest fires and how they become more virulent from year to year, confirming this phenomenon throughout the Mediterranean arc and in other areas such as Australia, South America, North America, South Africa, etc. The interrelation between the different parameters of topography, the multitude of meteorological variables and the complexity of forest fuels make the participation of specialised technical analysts with a great deal of experience in prevention and suppression highly recommendable. These personnel must at the same time have a very up-to-date knowledge of new technologies that can facilitate their work. It is vital that the maximum amount and the highest quality of information can be collected and properly analysed from the area where a forest fire is occurring (Castellnou et al., 2021).



- Because of the data on ratio of spread, estimated isochrones, fire intensities, resulting severity maps, accessibility according to the road network and accesses, it can be seen that the second fire was out of suppressing capacity from the very first moments it started. It is therefore understandable that the suppressing team was able to carry out small containment manoeuvres without endangering their integrity and safety and that they were successful. It should not be forgotten that at the same time, urban and military structures were being affected and the demand for resources meant that the forest area could not be attended to in a more substantial way. It is recommended that urban, military, industrial and communication infrastructures, etc., have effective passive self-protection elements against forest fires, thus reducing the resources required for suppression and defence in order to protect them.
- In the Urban-Forest interface it is recommended the construction of firebreaks, areas of less flammable vegetation, continuous water supply systems in hydrants with adequate pressure, and adequate awareness and training of the population is vital to achieve more resistant areas (Pastor et al., 2020).
- In view of the perimeter areas that have not been affected by forest fires, it is understandable that it is practically unfeasible to manage the entire landscape to make it more resistant and resilient to forest fires. This is why proper landscape prevention planning is required with the participation of all stakeholders (forest services, fire services, landowners, affected population, Municipal, Prefecture or National administrative managers, etc.). Areas (strategic management zones) should be identified where economic resources are concentrated to achieve low fuel load areas that can be maintained with the use of technical fire or managed livestock. These strategic zones should compartmentalise the landscape to create areas of opportunity and safe areas for forest firefighting resources (Madrigal et al., 2019).
- It should be developed a methodology for taking images and videos that could facilitate subsequent analysis with the aim of learning and generating lessons learned. It is very useful to use applications that facilitate the geopositioning of the exact location and orientation at the time the video or image is taken. At the same time, it is recommended that images and videos can provide information on situational awareness of relevant aspects of the wildfire. It is better to obtain images and videos that are panoramic and show the perimeter clearly, the smoke plume, fire conditions, etc.
- There are also Forester Engineers and Meteorologists in the Hellenic Fire Service who can be involved and create similar reports for all the other forest fires that occurred in Greece during fire season 2023. Keeping detailed data and making analytic reports can help to understand the fire behaviour of forest fires and be more prepared for the future challenges.



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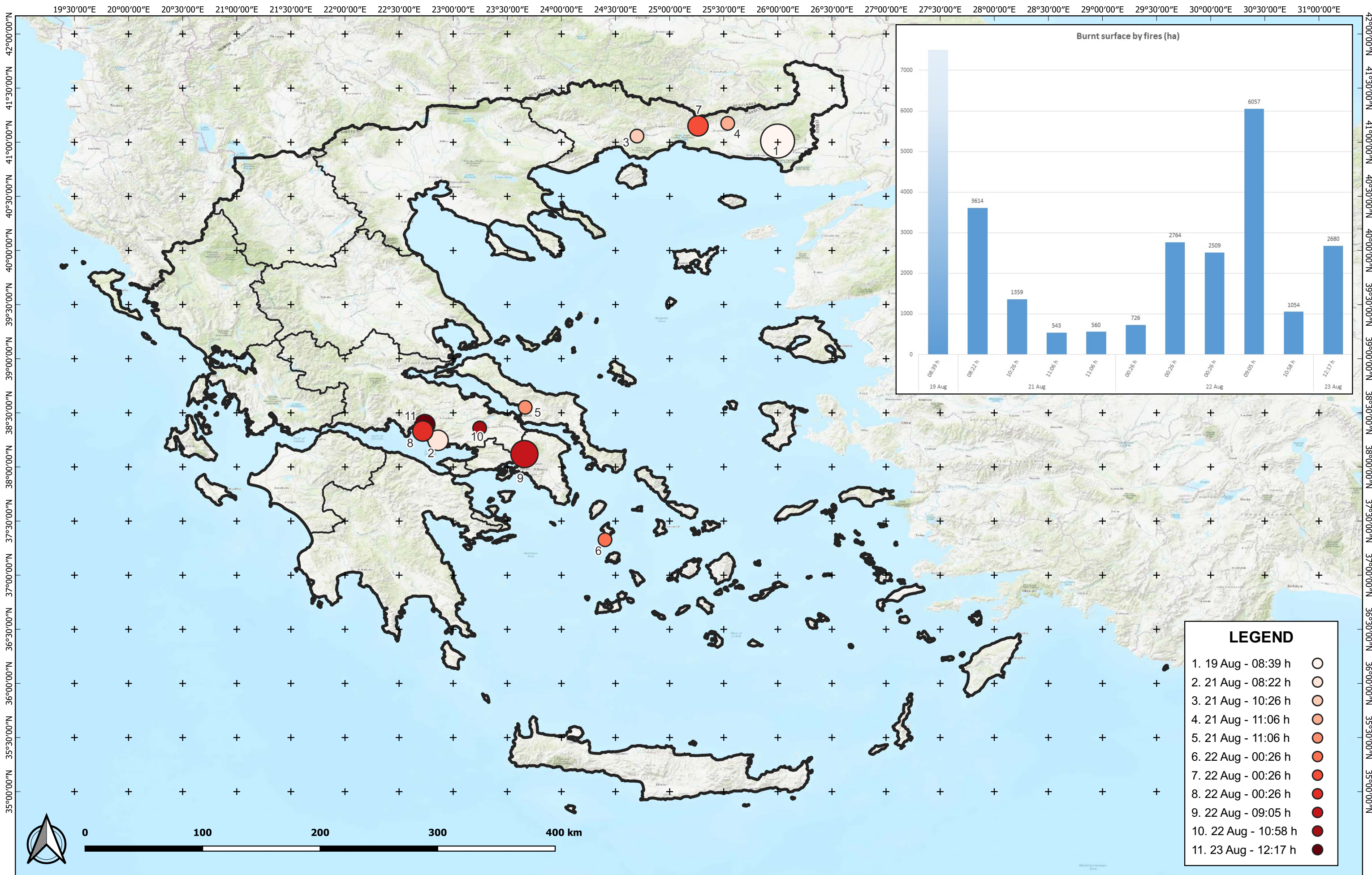
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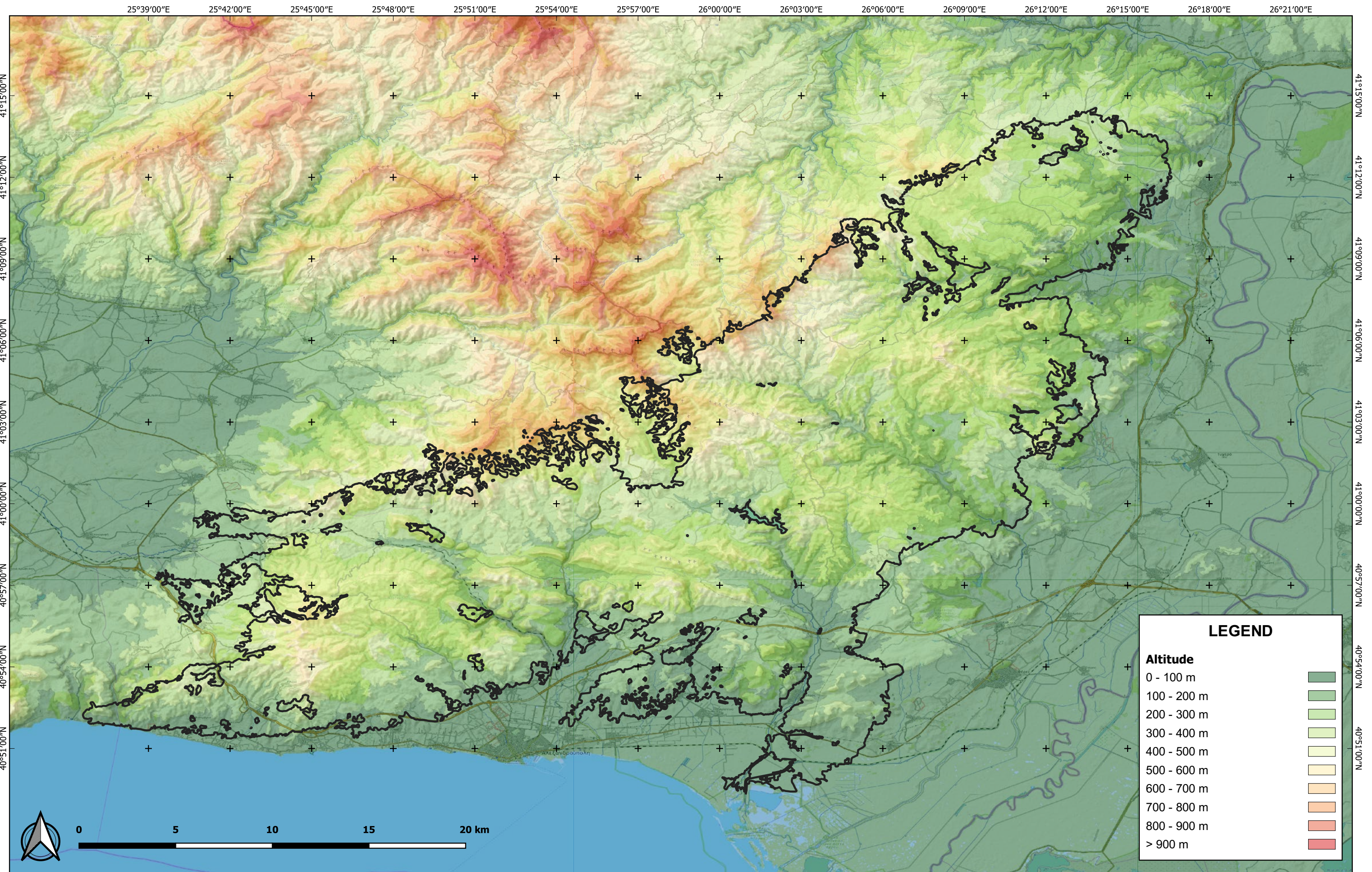


ANNEX MAPS

1. MAP 1: Big fires in Greece in August 2023.
2. MAP 2: Altitudes.
3. MAP 3: Aspects.
4. MAP 4: Slopes.
5. MAP 5: Vegetation CORINE Land Cover Classes.
6. MAP 6: Vegetation.
7. MAP 7: Isochrones and burned area growth 21 and 22 August 2023.
8. MAP 8: Isochrones and burned area growth Alexandroupolis fire.
9. MAP 9: Burn severity.







FOREST FIRES ASSESSMENT
AND ADVISORY TEAM

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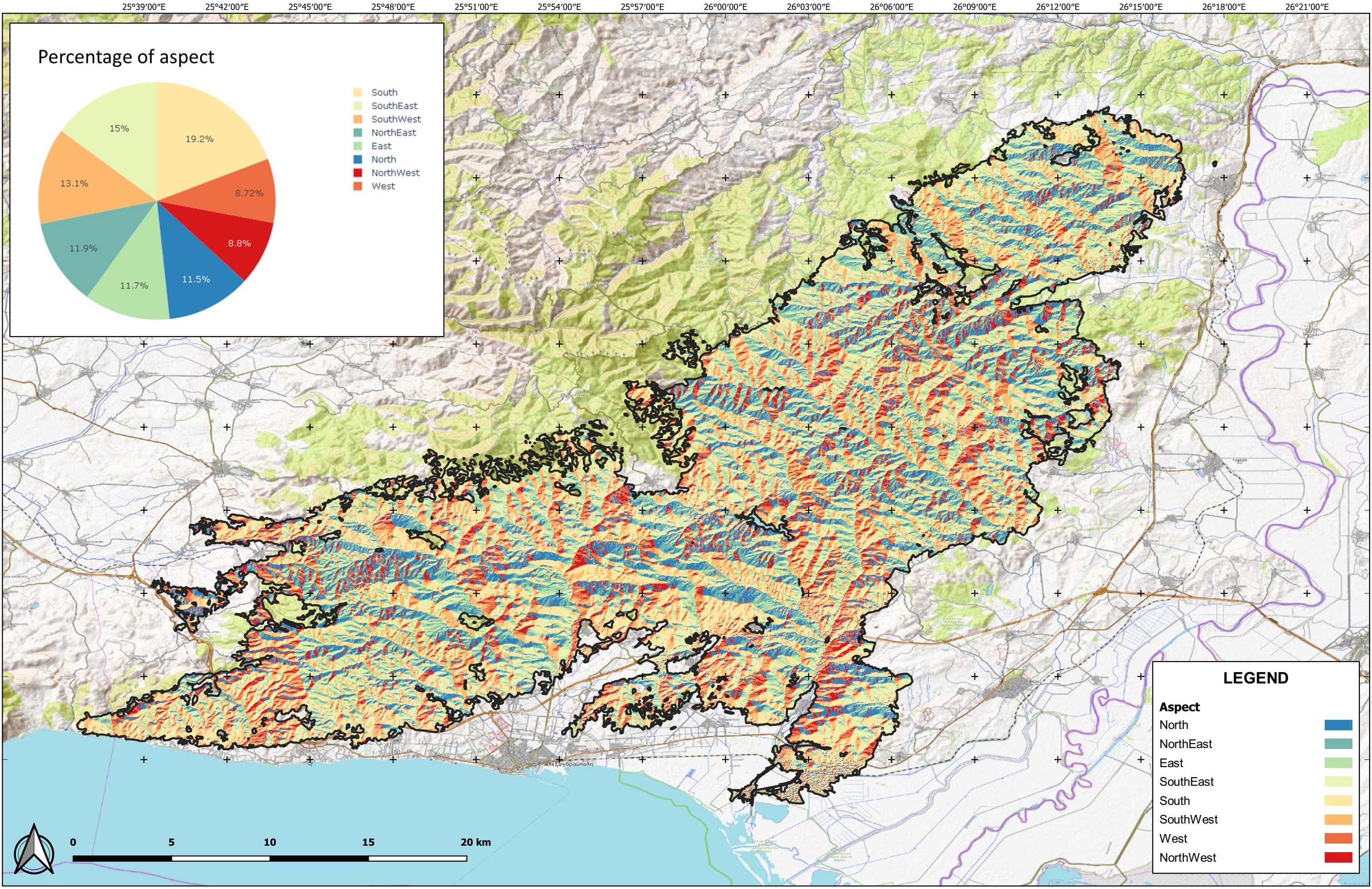
2023-10-06

Map:

Alexandroupolis fire
Altitude

Source:

ALOS DSM: Global 30m
Copernicus EFFIS



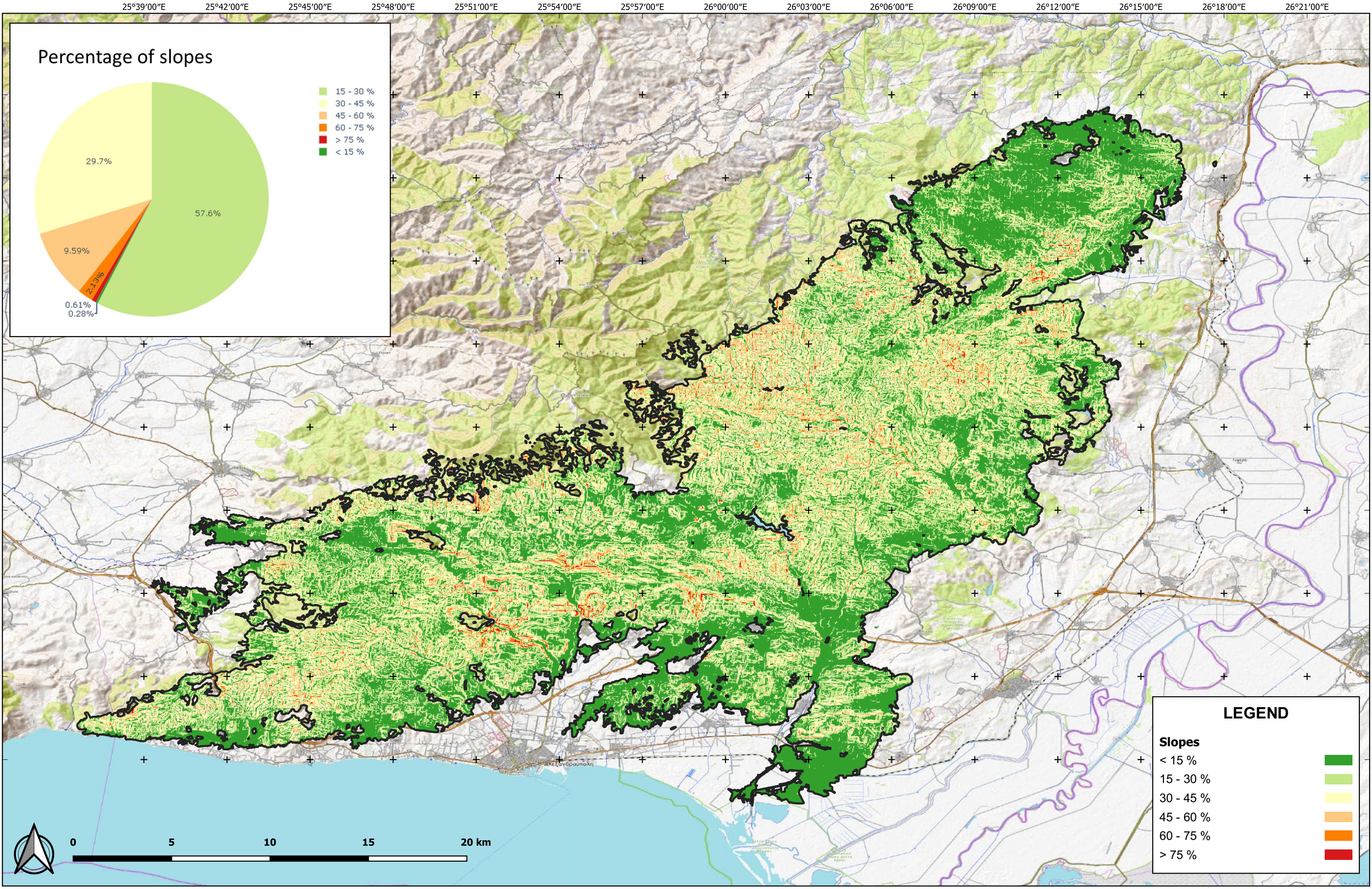
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AND ADVISORY TEAM

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Alexandroupolis fire
Aspect

Source:
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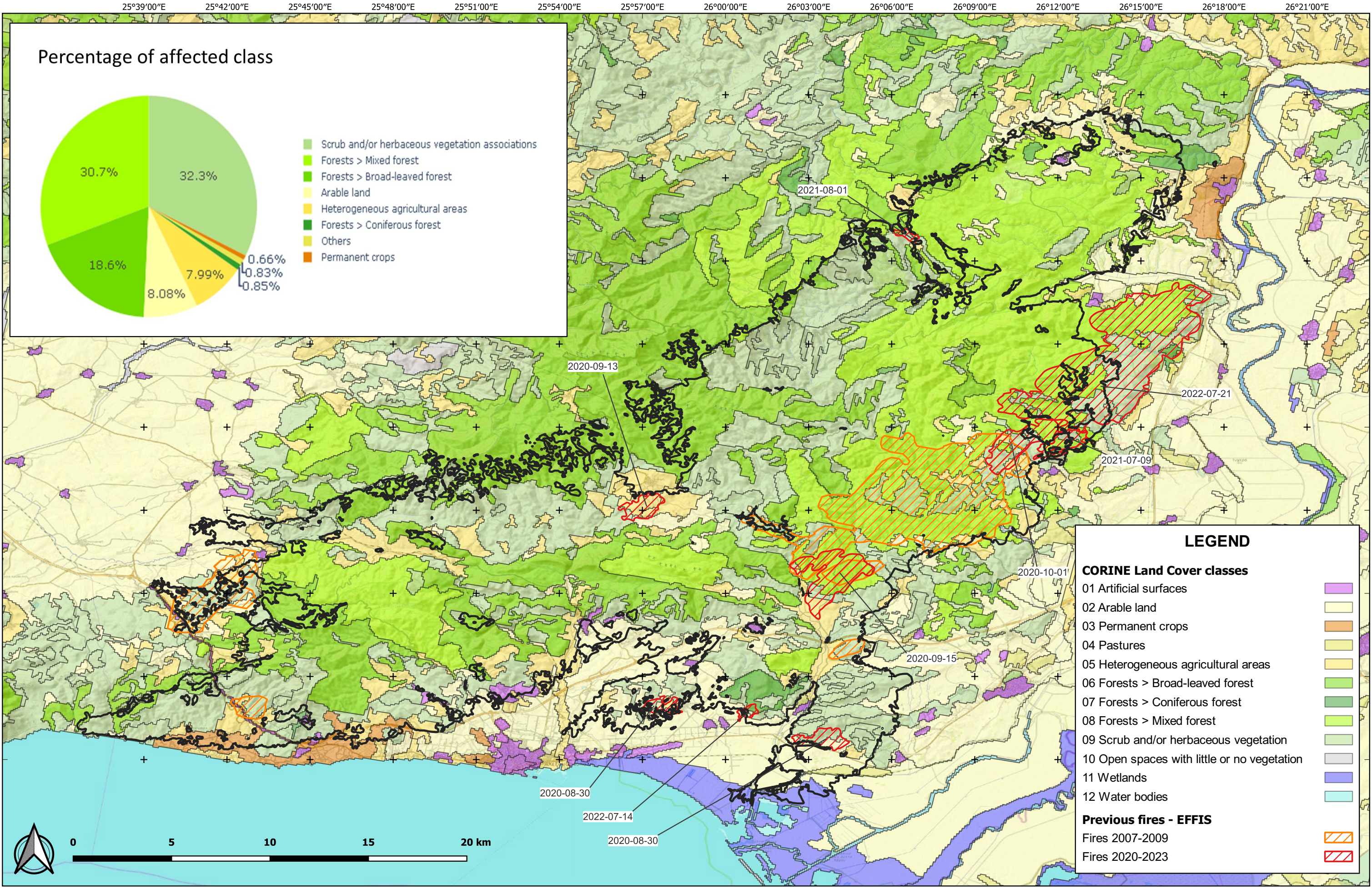
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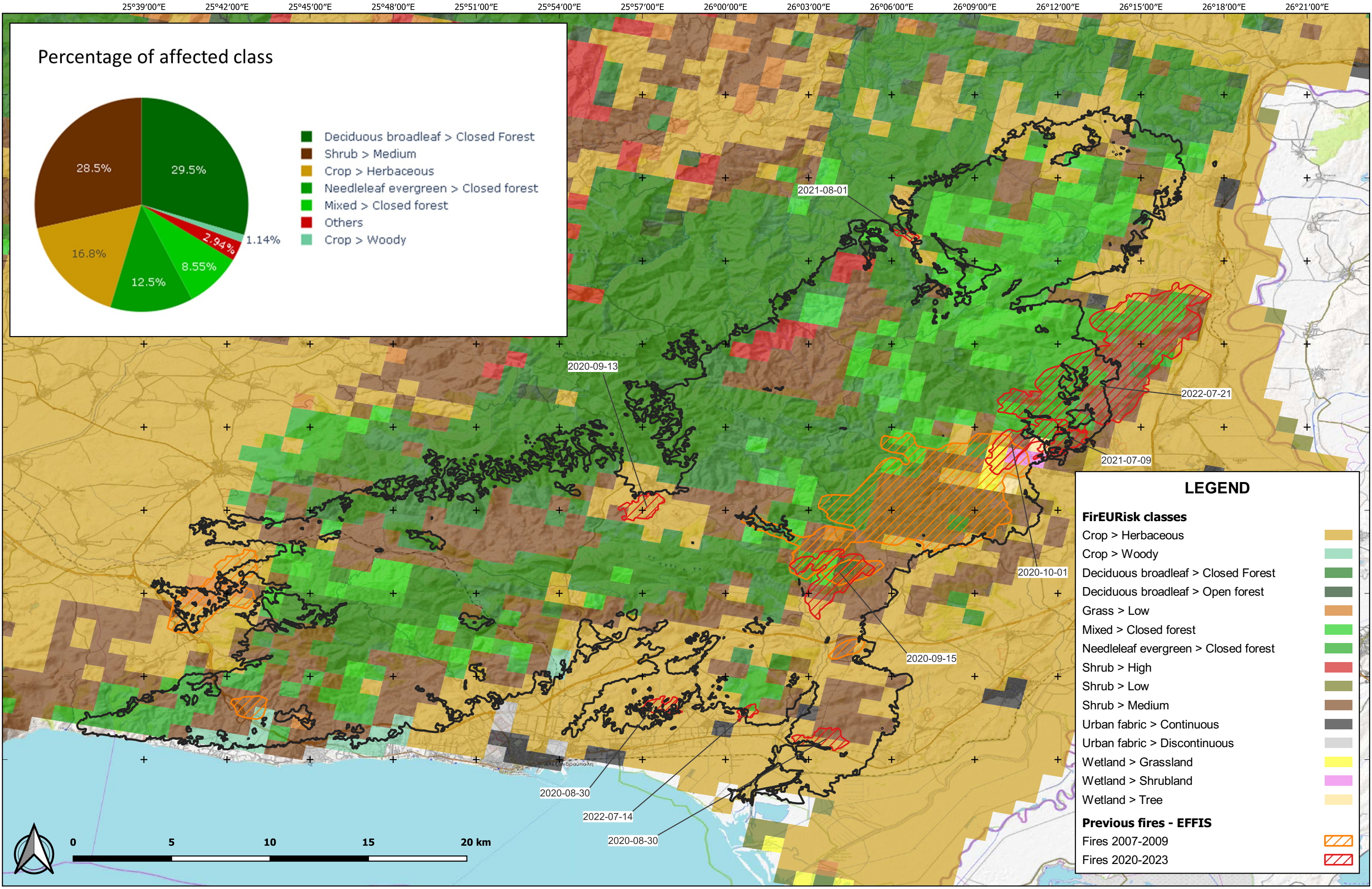
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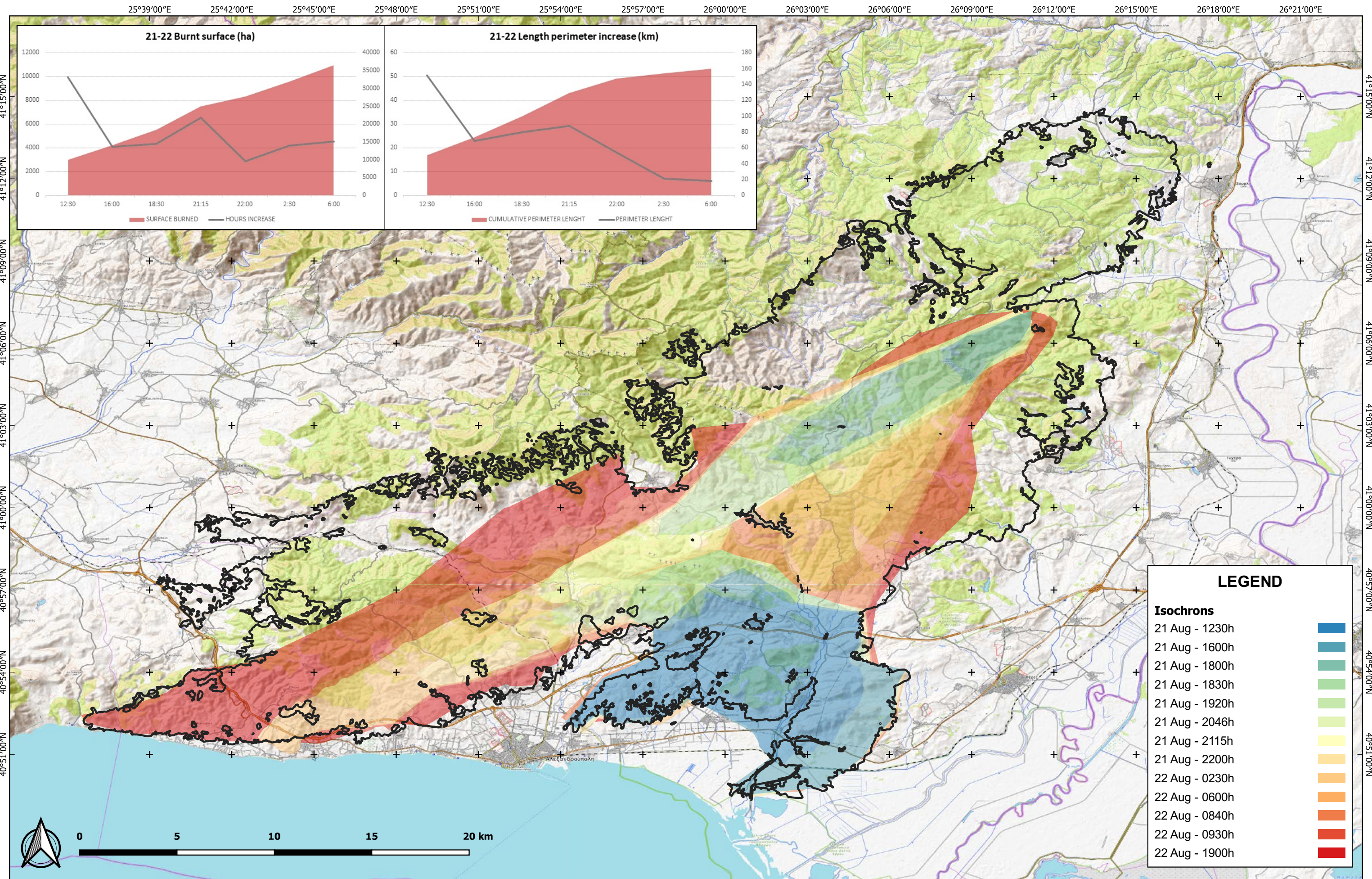
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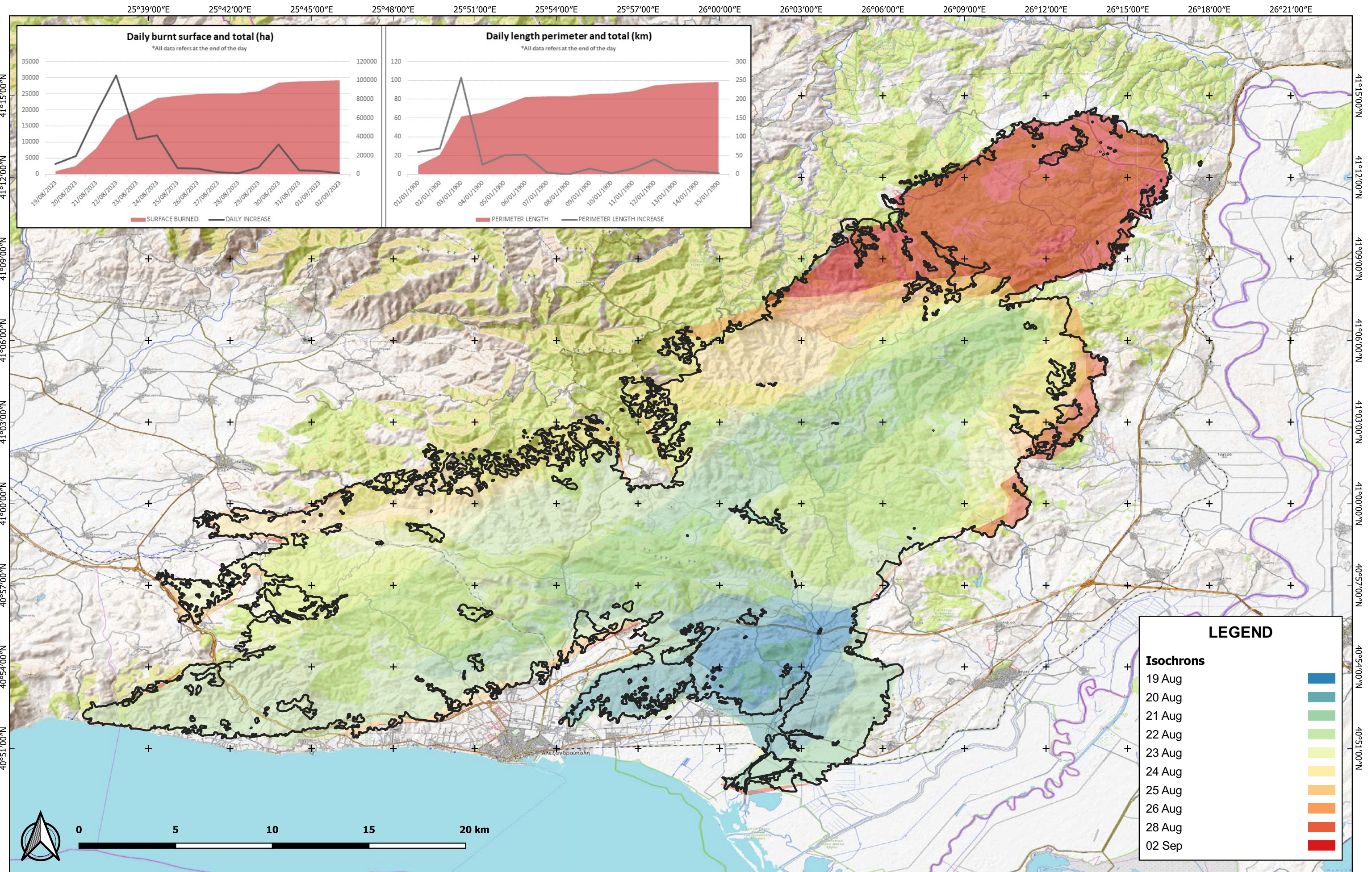
Map:
Alexandroupolis fire
Slopes

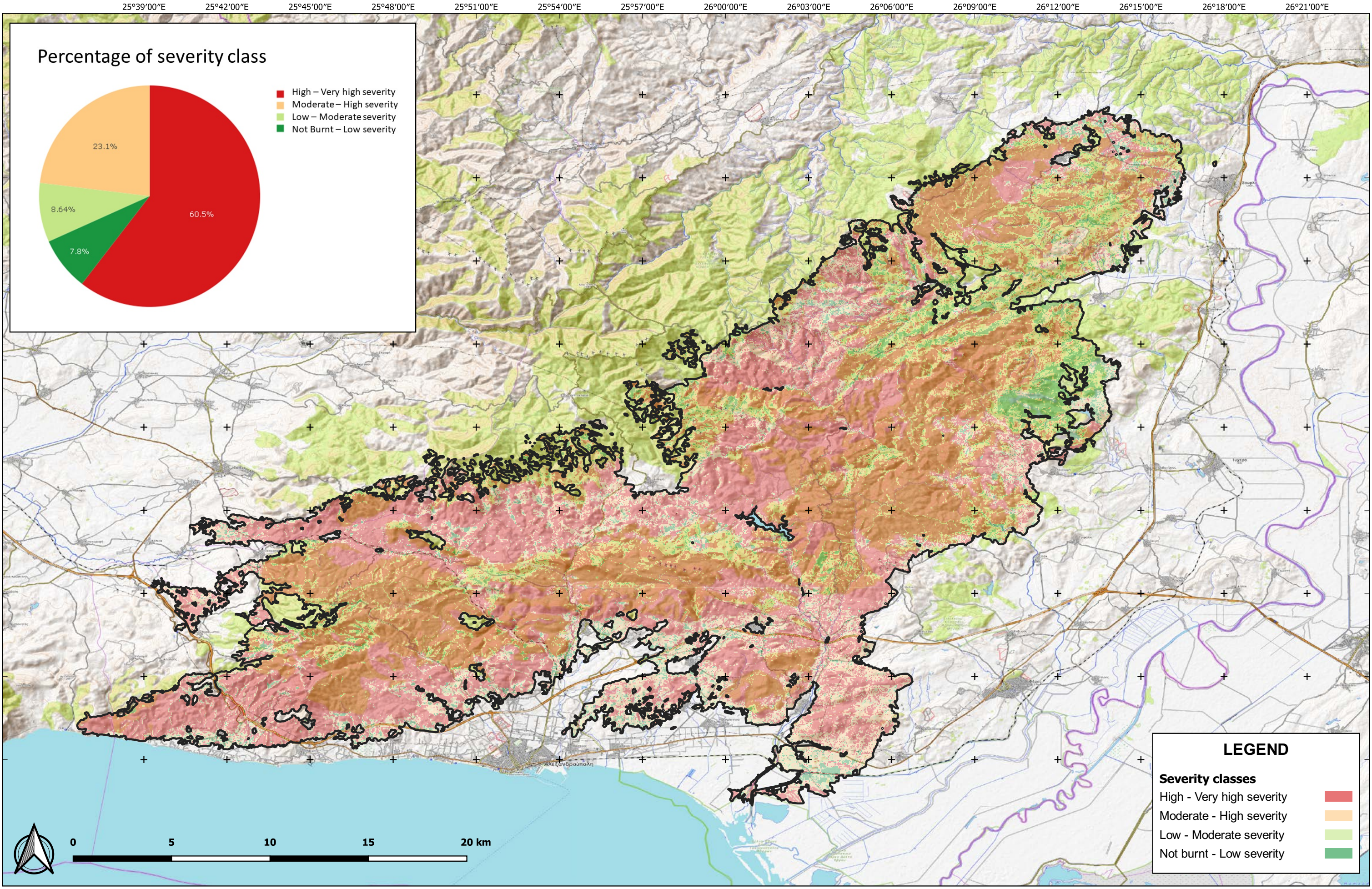
Source:
ALOS DSM: Global 30m
Copernicus EFFIS











FOREST FIRES ASSESSMENT
AND ADVISORY TEAM

WGS 84
1:125.000

Date:
2023-10-06

Map:
Alexandroupolis fire
Burn severity

Source:
Botella & Fernández, 2017
Copernicus EFFIS