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The Predictability of the Synoptic-Scale Fire Weather Conditions during the 2018 Mati Wildfire †

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Abstract: Forecasting and characterizing fire weather conditions over a region days in advance is of great importance for developing early warning systems and supporting effective wildfire management. Furthermore, it is important for increasing awareness and preparedness of all the involved entities, including both the public and practitioners. In addition, considering climate projections over the Mediterranean, which indicate an environment more conducive to wildfire activity, the need for timely forecasting of extreme fire weather days becomes increasingly urgent. In this work we present an application of the newly developed fire weather forecasting framework that employs the concept of critical fire weather patterns on the 2018 Mati wildfire. Within our fire weather forecasting framework, we assign the large-scale circulation pattern to one of the predefined critical fire weather patterns of Greece which are associated with different levels of fire danger based on the dominating fire weather conditions and expected fire behavior. For the purpose of this study, we use historical forecast data to assess the predictability of the synoptic-scale fire weather conditions using the critical fire weather patterns, and we discuss the main advantages of the presented forecasting framework. This fire weather forecasting framework is applied operationally by the METEO Unit of the National Observatory of Athens within the frame of the "FLAME" project since the 2022 fire season in Greece.

Keywords: critical fire weather patterns; fire weather; forecasting; fire danger; early warning

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1. Introduction

Fire is an integral component of Mediterranean ecosystems [1,2]. However, recent destructive wildfires (2017—Portugal; 2018, 2021—Greece, 2022—Spain and France) indicate the emergence of novel fire regimes, characterized by high-intensity burning and extreme fire behavior [3]. Among the factors influencing the timing, size, and intensity of wildfires, weather is perhaps the most well-documented [4].

While the importance of weather to wildfire activity has been documented since the 1930s, it was Schroeder who first examined in detail the synoptic weather patterns that drive surface fire weather conditions in the United States of America (USA) [5]. A few decades later, Skinner et al. and Crimmins identified and presented synoptic climatologies of fire weather conditions across Canada and the southwestern United States, respectively [6,7]. In more recent studies, the link of particular synoptic weather patterns with surface fire weather and/or wildfire activity has been extensively examined via using different methods to classify and characterize the synoptic conditions across Portugal, Alaska, Greece, western Canada, Spain, and northwestern United States [8–14]. Previous studies have identified that the most adverse fire weather conditions are usually expressed as combinations of high temperatures, low humidity, strong winds, and atmospheric instability. These conditions are typically associated with upper-tropospheric ridges or blocking patterns, as well as the breakdown of upper-tropospheric ridges downstream of approaching upper-tropospheric troughs. It is important to note that the magnitude and persistence of upper-tropospheric ridges/blocking play a key role in the development of extreme fire weather conditions via regulating the drying of fuels and, therefore, the landscape flammability. In addition, the breakdown of such ridges/blocking patterns downstream of an approaching upper-tropospheric trough is often associated with enhanced winds and the development of atmospheric instability. These conditions in combination with hot and dry surface/near-surface conditions can lead to extreme fire weather [6,15–19]. Based on data for the period 2006–2021 from the European Forest Fire Information System (EFFIS; https://effis.jrc.ec.europa.eu/; accessed on 2 August 2023), wildfires in Greece burn an average of 44,000 ha annually, resulting in significant socioeconomic and environmental impacts, including human casualties [20]. During this period, Greece experienced some of the country's most destructive fire seasons in terms of burnt area, with the most exceptional being the 2007 and 2021 fire seasons [19,21]. More worryingly, Greece experienced the deadliest wildfires of the country's recent history during the 2007 and 2018 fire seasons, in the Peloponnese and Attica regions, respectively (e.g., [21,22]). These recent events highlight the need for advancing our knowledge to develop early warning systems and support effective wildfire management. This effort will contribute to increasing awareness and preparedness of all the involved entities, including both the general public and practitioners.

In this work, we present an alternative fire weather forecasting framework that utilizes advanced machine learning methods to derive synoptic-scale drivers of fire weather in Greece. Within this framework, we define the critical fire weather patterns of Greece, and we show an application of this approach during the 2018 Mati wildfire. Furthermore, we assess the predictability of the synoptic-scale fire weather conditions, and we discuss the added value of our forecasting approach. We anticipate that the presented results could support more effective fire management by providing valuable information to practitioners regarding the anticipated dangerous fire weather conditions several days in advance. Furthermore, the engagement of the public should not be neglected since this approach could be used for increasing public awareness and preparedness via timely communication of fire weather information to the public.

In Section 2, we present the data and methods that we use in this study. In Section 3, we present an application of the critical fire weather patterns of Greece during the 2018 Mati wildfire, discussing the characteristics and forecasting challenges. In Section 4, we provide a summary of our main findings, discussing their importance for awareness raising, preparedness, and management.

2. Data and Methods

2.1. Atmospheric Data and Classification of Weather Patterns

We define the critical fire weather patterns of Greece by applying state-of-the-art machine learning techniques on ERA5 reanalysis atmospheric data, provided by the European Center for Medium-range Weather Forecasts (ECMWF) [23]. ERA5 data have a spatial resolution of $0.25^\circ \times 0.25^\circ$. We use the data from June–October 1979 to 2019 over Europe (25° W–45° E, 20° N–75° N). We use the period June–October as it coincides with the highest wildfire activity in Greece. We employ daily mean 500 hPa geopotential height (Z500) data to define the most representative synoptic weather types that influence weather in Greece. To classify the synoptic weather types over Europe, we employ the SOM approach on daily mean Z500 from the ERA5 reanalysis dataset during 1979–2019 [24]. The SOM computations are performed using the SOMPY python library version 1.0 (available online at https://github.com/sevamoo/SOMPY, accessed on 2 August 2023) and the daily mean geopotential height data are computed using the Climate Data Operators (CDO), version 2.0.0 (https://code.mpimet.mpg.de/projects/cdo, accessed on 2 August 2023). After testing the sensitivity of our analysis to the number of nodes that will be used for obtaining the continuum of synoptic weather patterns in SOM, we opt for 36 nodes. Based on the characteristics of these 36 archetypes of synoptic weather patterns and their similarities, we group nodes into five patterns that we refer to as the critical fire weather patterns. For more details on this methodology and the link of the critical fire weather patterns to different fire weather conditions and different levels of fire danger, we refer the reader to [25].

2.2. GEFS Reforecasts

For the purpose of our analysis, we use retrospective forecasts of Global Ensemble Forecast System Version 12 provided by NOAA. This reforecast dataset consists of one control simulation and four ensemble members, with a forecast length of 16 days. We illustrate the predictability of a synoptic weather pattern by analyzing the five-member mean GEFS reforecasts at 12Z at different lead times. As a reference period for computing the anomalies, we use the standard period spanning from 1981 to 2010 from ERA5 data. In this study, we illustrate an application of the critical fire weather patterns during the wildfire in Mati, Attica, on 23 July 2018, and we assess the predictability of the related synoptic-scale fire weather conditions in GEFS reforecasts.

3. Results

3.1. Critical Fire Weather Patterns of Greece

The grouping of nodes following our SOM analysis results in the critical fire weather patterns (CFWPs), which are presented in Figure 1. We note that CFWP-1 (Figure 1a) and CFWP-2 (Figure 1b) are mainly associated with below-average geopotential heights in most parts of Europe. These patterns are mainly associated with below average temperatures and wetter conditions for most parts of Greece [25]. On the other hand, in CFWP-3, we find above-average geopotential heights for most of Europe, while a short-wave trough is found over the Balkan states. This pattern is primarily linked to above average temperatures and drier conditions across the eastern and northern continental parts of Greece, and Crete, while there is increased potential for the development of atmospheric instability. Thus, this pattern is locally linked to hot-dry and windy conditions [25]. The CFWP-4 is characterized by a long-wave ridge over southeastern/eastern Europe and a long-wave trough over northwestern/western Europe, representing a rather typical heatwave pattern for Greece. This pattern is accompanied by substantially above-average temperatures and dry conditions [25]. Finally, the CFWP-5 is characterized by the dominance of above-average geopotential heights that extend from the N. Atlantic to the Balkan states and eastern Europe, while lower geopotential heights are found over Scandinavia. This pattern is associated with substantially above-average hot-dry-windy conditions mainly across the eastern parts of Greece, primarily driven by the enhanced north-northeasterly winds. This pattern can be characterized as a typical "Etesian winds" synoptic pattern.

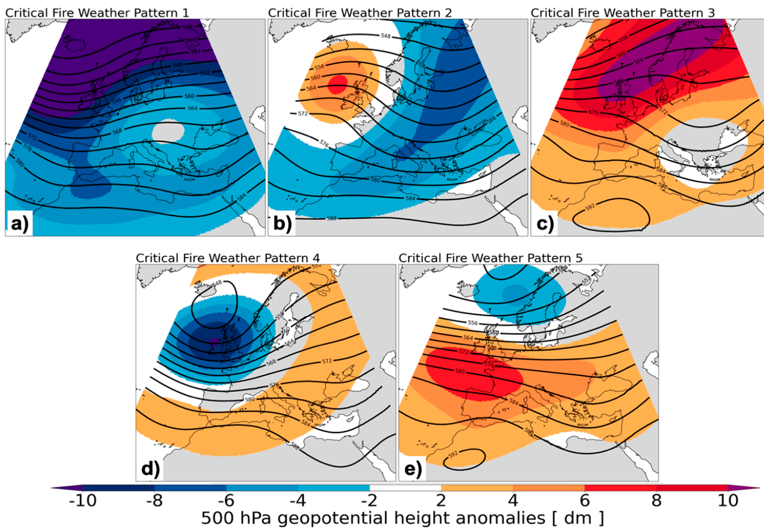

Figure 1. The five (**a**–**e**) critical fire weather patterns (CFWPs) of Greece. The shading denotes the anomalies of geopotential height at 500 hPa with respect to the 1981–2010 period and the contours show the geopotential height at 500 hPa. Figure adapted from [25].

3.2. Synoptic-Scale Fire Weather Conditions during the 2018 Mati Wildfire

The Mati wildfire ignited on 23 July 2018 at 13:49 UTC 5 km to the west of the Mati coast. Using GEFS retrospective forecast of Z500 for 23 July 2018 for 12Z, the synoptic pattern is characterized by the collapse of a short-wave ridge while an upper-tropospheric trough is approaching Greece from the west (Figure 2). As a result of this circulation pattern, an enhanced gradient of Z500 isoheights is found over Greece, denoting enhanced westerly winds.

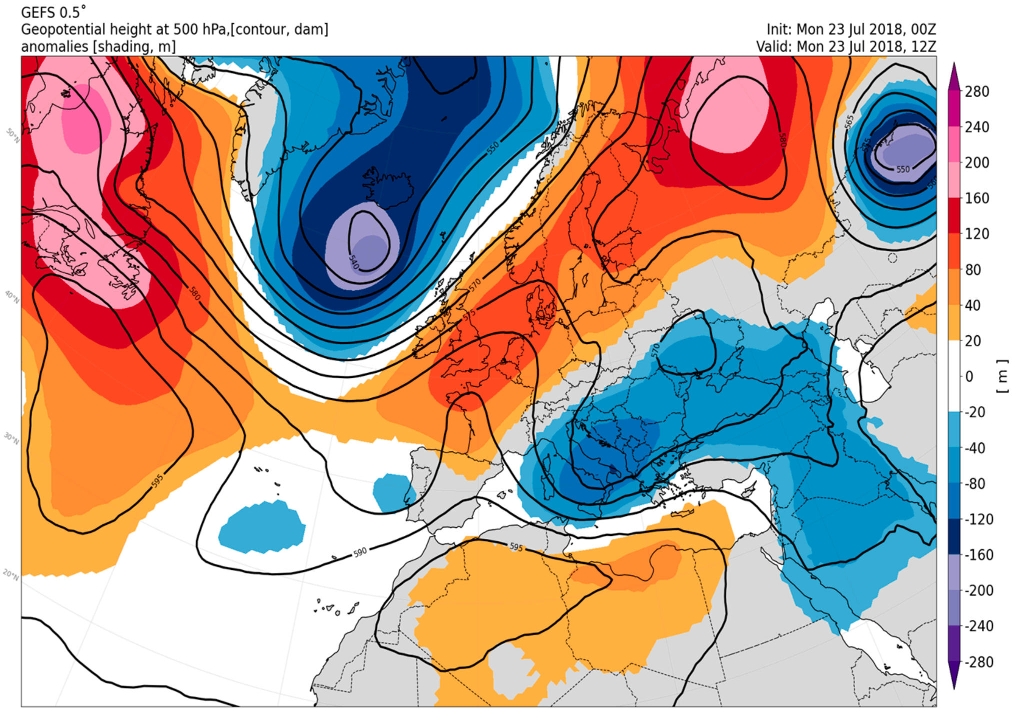

Figure 2. GEFS reforecast of geopotential height at 500 hPa (contours) for 23 July 2018, 12Z initialized on 23 July 2018, 00Z. The shading denotes the geopotential height at 500 hPa anomalies with respect to the 1981–2010 period from ERA5 data.

3.3. Predictability of the Synoptic-Scale Fire Weather Conditions during the 2018 Mati Wildfire

We objectively assess the synoptic-scale fire weather conditions during this day by using the SOM-based classification. According to the SOM-based classification, the synoptic weather pattern on 23 July 2018 is categorized as CFWP-3. This pattern suggests elevated fire danger across the eastern continental parts of the country due to a combination of hot, dry, and windy conditions [25].

We assess the predictability of this event by analyzing ensemble mean GEFS forecasts of Z500 for 23 July 2018, 12Z, with lead times ranging from −1 day to −12 days (Figure 3). Our analysis shows that with lead times ranging from −12 to −8 days, there is low predictability of the large-scale circulation. This low predictability could be linked to uncertainties in the circulation pattern over the higher latitudes of the North Atlantic and further downstream implications on the waveguide. However, with lead times ranging from −7 days to −1 day, there is high predictability of the synoptic weather pattern, with even smaller discrepancies in the forecast beyond lead times of −5 days.

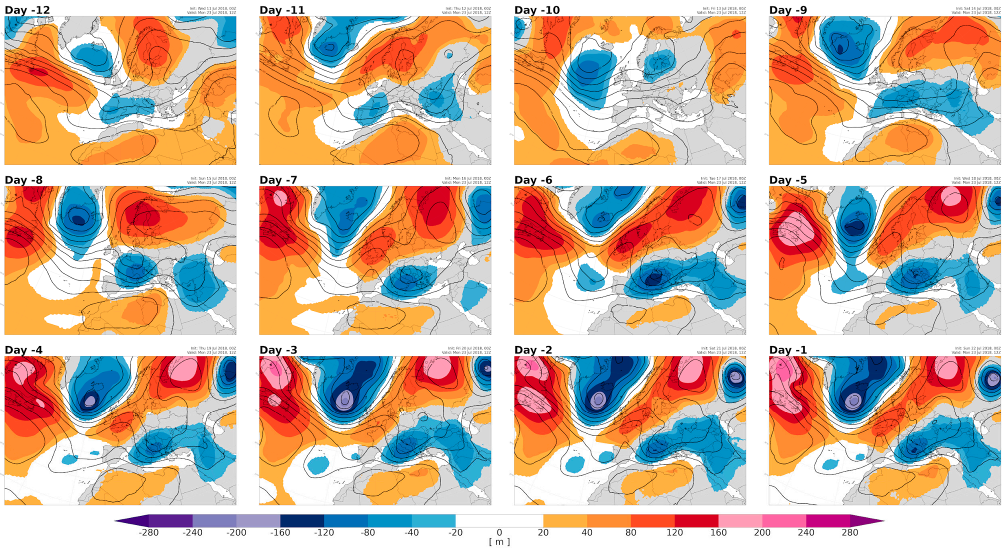

Figure 3. GEFS reforecast of geopotential height at 500 hPa (contours) for 23 July 2018, 12Z with lead times ranging from −12 days to −1 day. The shading denotes the geopotential height at 500 hPa anomalies with respect to the 1981-2010 period from ERA5 data.

4. Conclusions

Overall, our analysis shows that using the critical fire weather patterns and GEFS ensemble forecasts of Z500, the extreme fire weather conditions and the accompanied elevated fire danger of 23 July, 2018, that played a key role to the deadliest wildfire in Greece were well predicted 7 days in advance. These findings highlight the usefulness of our forecasting framework for awareness raising, preparedness, and effective fire management.

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Data Availability Statement: ECWMF data are available at https://cds.climate.copernicus.eu/ (accessed on 2 August 2023). GEFS retrospective forecasts are available at https://noaa-gefs-retrospective.s3.amazonaws.com/index.html#GEFSv12/reforecast/ (accessed on 2 August 2023).

Conflicts of Interest: The authors declare no conflict of interest.

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