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Fire Weather Assessment of Future Changes in Fire Weather Conditions in the Attica Region †

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Abstract: Under the framework of the European project "FirEUrisk", the present work aimed to spatially assess the climate change signal of fire weather danger in the Attica region at a high resolution of 5 km. For this purpose, a methodology was applied to investigate the projected changes in fire weather conditions under two emission scenarios and two future periods. The fire weather assessment was based on the fire weather index system and other related indices. The calculated indices were derived from high-resolution validated simulations. Large increases in FWI90 were observed during all periods and under both emission scenarios, mainly in the eastern parts. It is estimated that the northeastern parts will encounter more than 70 days of extreme fire weather, which corresponds to a future change of an increase of more than 45 days compared to the historical period. A change of more than 50% in the ISI will be observed in almost the entire region in the near future under RCP4.5, while this change is restricted mostly to the eastern Attica region under RCP8.5 in both periods.

Keywords: WRF; fire weather index; initial spread index; RCP4.5; RCP8.5; climate change; EC-EARTH; fire danger

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1. Introduction

The weather in Greece is typically Mediterranean, with long periods of sunshine and hot, dry summers as well as wet, mild winters. As a result, the occurrence of wildfires in Greece is heavily influenced by these weather and climate patterns. In recent years, the Attica region in eastern Central Greece has experienced a considerable number of devastating wildfires (e.g., Mati in 2018, Mount Penteli in 2009 and 2022, and Parnitha in 2021) that have caused significant socio-economic and environmental impacts [1,2].

It was found that there is limited research (e.g., [3,4]) when it comes to studying the impact of climate change on fire weather, particularly at a higher spatial resolution, as the complexity of the region creates significant climatic variations. These features led to the need to investigate how climate change could impact the fire weather conditions of the most populous area of Greece, that of the Attica region, on a local scale. It should be mentioned that this work is also complementary to a recent study by Politi [5], who analyzed fire weather projections at a high spatial resolution for the area of Greece.

In the context of fire weather assessment, the projected changes in fire weather conditions were investigated in the Attica region at a high resolution of 5 km, focusing on two different climate scenarios and future periods. For this purpose, the daily fire weather index (FWI, [6]) and other derived indices were calculated using validated dynamically downscaled climate datasets produced by the Weather Research and Forecasting (WRF-ARW) model's simulations. This study is also part of the European project "FirEUrisk", which aims to develop evidence-based strategies for managing wildfires and increasing resilience to these events across Europe.

2. Materials and Methods

WRF Model Setup

The dynamical downscaling technique was applied through the non-hydrostatic WRF model (version 3.6.1) [7]. The spatial configuration (Figure S1a) along with the description of the model setup can be found in detail in [8–12]. These extensively attentive validation studies proved the credibility of the downscaling process of capturing the historical spatio-temporal patterns of climate variables. The initial and boundary conditions were derived from the EC-Earth model [13] climate simulations for RCP4.5 and RCP8.5 [14,15]. The model's simulations were divided based on three time periods: the historical or reference (1980–2004), near future (2025–2049), and far future (2075–2099) periods.

The approach used for the estimation of fire weather conditions in this study followed the application of the percentiles method, which is described in the study of Varela et al., 2018 [16] and takes into consideration the climate variability of the country. In this way, the current analysis aimed to overcome certain limitations that arise from using fixed FWI thresholds, proposed by the European Forest Fire Information System (EFFIS), https://effis.jrc.ec.europa.eu/ (accessed on 2 April 2023) network; also see Table 1.

Table 1. The classification of values for the FWI and its sub-component the ISI.

FWI Classes by the EFFIS	FWI Percentiles by Varela et al. [16]	ISI Classes by the EFFIS
Very low (<5.2)		Very low < 3.2
Low (5.2–11.2)	Low 25th percentile	Low 3.2–5
Moderate (11.2–21.3)	Moderate 50th percentile	Moderate 5–7.5
High (21.3–38)	High 75th percentile	High 7.5–13.4
Very high (38–50)		Very high 13.4–30
Extreme (≥50)	Extreme 90th percentile	Extreme >30

Calculation of the FWI was performed using the package CFFDRS, https://r-forge.r-project.org/projects/cffdrs/ (accessed on 2 November 2022) of R statistical computing software using the daily values of maximum temperature, relative humidity, wind speed, and total daily precipitation. A short description of the indices used in this study can be found in Table 2 below:

Table 2. Description of the examined indices, used in this study.

Indices	Description
FWI90	The 90th percentile of the FWI
FWI90NR	Number of days above FWI90 (as extreme fire weather)
FWI90NRCD	Maximum number of consecutive days above FWI90
ISI	Initial spread index

In the final step, the 25-year mean of these indices was calculated for every land grid point to spatially represent the climate change signal of fire weather conditions at high resolution.

3. Results and Discussion

This section demonstrates the results with the spatial distribution of the projected changes in fire weather danger at a high spatial resolution, as derived from the calculation of FWI indices and the specific 90th percentile indices. As illustrated in Figure 1, during the historical period, values of the extreme percentile (FWI90) between 50 and 70 are observed in the northern Attica region, while values of FWI90 greater than 75 are observed over the rest of the region, with higher values in the western part of the region. In the future periods, large increases in FWI90 are observed during all periods and under both emission scenarios, with the stronger changes focusing on the eastern and western parts of the Attica region.

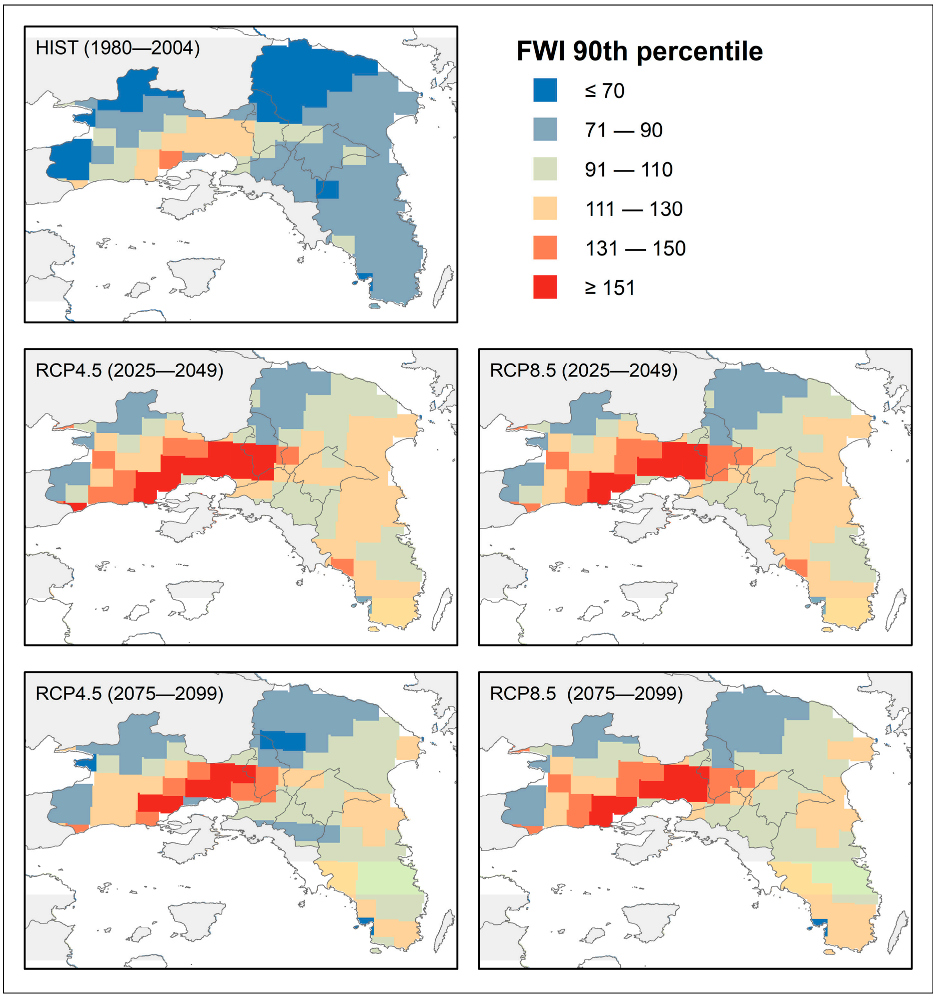

Figure 1. FWI threshold value of the 90th percentile for the historical, near future, and far future periods for each emission scenario for the Attica region.

Regarding the number of days above the threshold value (90th percentile FWI of the historical period), it was observed that no more than 30 days were found in the entire Attica region during the historical period, as indicated for the area of Greece in the initial study of Politi et al., 2023 [5]. However, the projected changes pointed out an increase in the number of days (Figure S2), which is more evident in the near future period in both scenarios and in the far future period under RCP8.5. Furthermore, the northern parts of the Attica region will experience more than 70 days of extreme fire weather during the fire seasons, thus representing a future change with an increase of more than 45 days compared to the historical period. The projection in the other parts of the region gave an estimate between 41 to 70 days of extreme fire weather, with an exception during the far future and under RCP4.5 where less than 40 days are observed in the central western part of the region.

As depicted in the spatial analysis in Figure S3, the north-eastern part of the Attica region will experience a higher future change in extreme consecutive fire weather days above the 90th percentile of the historical period (with more than 22 days) compared to the historical period in the near future. It was also observed that more than 14 consecutive days of extreme fire weather are expected during all periods and scenarios in the eastern Attica region.

As far as future changes in the ISI are concerned, a major part of the Attica region is characterized by a high initial spread index to very high in the western part during the historical period, as illustrated in Figure 2. A change of more than 50% in the ISI over almost the entire region (more than 60% in the eastern Attica region) in the near future under RCP4.5 was noticed, while this change is restricted to the eastern Attica region under RCP8.5 in both periods. Finally, changes of the ISI are lower in the far future and under RCP4.5.

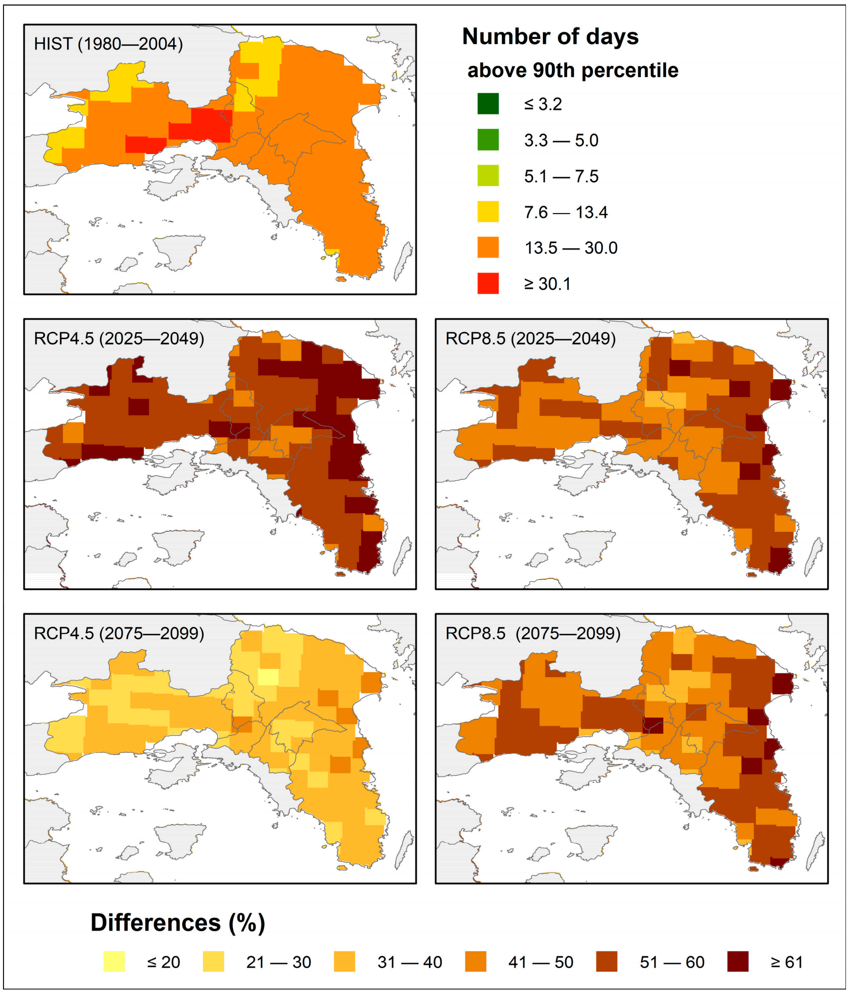

Figure 2. The mean value of the initial spread index for the historical period (top map) and future changes under RCP4.5 and RCP8.5 (in %) for the near and far future periods with respect to the historical period (middle and bottom maps, respectively) for the Attica region.

As the FWI calculation is described by a multivariant dependence, these results could be attributed to several factors. Firstly, an increased change signal of maximum and minimum temperatures is reported in the study of Politi et al., 2022 [12], with the most pronounced changes predominantly over the eastern areas. Furthermore, the findings of Vlachogiannis [17], where the same data had been used for climatic multi-hazard risk assessment for the area of Greece, indicated that the probability of occurrence of extreme winds, which is an important factor influencing the rate of fire spread, is higher almost all over the domain (the Attica region included) in the near future under both scenarios compared to the far future period. In addition, the increased number of days with extreme fire weather can be related to the remarkable decrease in future precipitation in the north-eastern part of the Attica region under both periods and scenarios. These latest factors play the most important role, as precipitation and wind speed are the meteorological parameters with the highest impact on the index according to Karali et al., 2022 [8].

Overall, as this study focused on investigating the potential impact of climate change on fire weather danger in the Attica region based on the use of FWI thresholds, the results highlight areas of the region that are most prone to wildfire danger under a changing climate. The fixed FWI thresholds can lead to either overestimation or underestimation of fire danger in certain regions, as has been pointed out by Varela et al. 2018, due to climate variability created by the complex topography of this region. The study of Papagiannaki [18] also showed that the FWI critical values of the European system EFFIS are considered too low and therefore not representative of the conditions in Greece. Thus, the study proposes the application of the new method based on percentile indices that consider the unique physical characteristics of the study area along with the use of high spatial resolution climate data to provide more accurate FWI boundaries for different classes and, consequently, a clear benefit to the derivation of fire danger patterns under a changing climate. Consequently, this information could be taken into consideration by forest fire authorities in fire management planning.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/environsciproc2023026186/s1. Figure S1: (a) Modelling Domains: d01 refers to the outermost domain of 20 km and d02 to the nested domain of 5 km (region of Greece). This figure is obtained by Politi et al., 2022 [12]. (b) Area of Greece, in orange color for the Attica region; Figure S2: The number of days above 90th percentile (threshold value is set as 90th percentile of the historical period for the specific cell for all time periods) under the future emission scenarios in the near and far future periods for the Attica region; Figure S3: The maximum number with consecutive days above 90th percentile (threshold value is 90th percentile of the historical period for the specific cell) for historical period and RCP4.5 and RCP8.5 for the near and far future periods for the Attica region.

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

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