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Spatiotemporal analysis of fire danger extremes in Europe between 1980 and 2019: Preliminary results

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Abstract

This work summarizes preliminary results of a spatiotemporal analysis focusing on changes in the occurrence of fire danger extremes in Europe between 1980 and 2019. Extreme danger days were defined based on the daily severity rating exceeding the locally defined 95th percentile. For the 2001 – 2019 period, we show that extreme fire danger days and total burnt area have a positive relationship across Europe, albeit stronger in the eastern half of it. Trend analysis results indicate that extreme fire danger days have overall increased in Europe, with the largest increases found in the north-eastern regions. Further, we illustrate that these increases may be related to abrupt shifts in the means, especially over the south-west Mediterranean, and central and north-eastern Europe. These shifts took place primarily during the 1990s, marking large increases in the mean annual number of extreme fire danger days before and after the years of change. It is hypothesized that these abrupt shifts in fire danger extreme means could be associated with changes in the large-scale circulation of the atmosphere. Overall, the approach followed in the present study is novel as it has not been implemented in previous studies focusing on fire weather extremes. In that view, it complements existing studies and provides new insights into the spatiotemporal variations and changes of fire danger extremes in Europe.

1. Introduction

According to the European Forest Fire Information System, the 2021 fire season in Europe was the second worst on record since 2000 (San-Miguel-Ayanz et al., 2021). Large and extreme wildfires burnt more than 500,000 ha across 22 EU27 Member States, with Mediterranean countries experiencing the most damages. These wildfires are the latest in a series of catastrophic events that affected Europe in recent years. Some of the worst cases include the wildfires that occurred in Portugal (2003, 2005, and 2017), Spain (2006 and 2017), Greece (2000, 2007, and 2018), and Sweden (2018). Researchers argue that the frequency and intensity of such events have been increasing due to the more frequent occurrence of extreme fire weather (e.g., Abatzoglou and Williams, 2016; Bowman et al., 2017; Jolly et al., 2015).

In this work, we present preliminary results of a spatiotemporal analysis focusing on the occurrence of fire danger extremes in Europe between 1980 and 2019. Our analysis is based on the daily severity rating (DSR), a sub-component of the Canadian Forest Fire Weather Index System (CFFWIS; Van Wagner, 1987) that indicates fire suppression difficulty. Trend analysis was conducted to quantify long-term changes in the occurrence of fire danger extremes in Europe. In addition, we applied statistical change-point detection methods to identify and quantify abrupt changes in the occurrence of extreme fire danger days.

2. Data and methods

Daily, gridded DSR data were retrieved from the 0.25^o x 0.25^o spatial resolution GEFF-ERA5 reanalysis dataset of the CFFWIS (Vitolo et al., 2020), developed by the European Centre for Medium-range Weather Forecasts (ECMWF). The data cover spatially the European region from 25^o W to 40^o E and from 34 ^{o}N to 72 ^{o}N (Figure 1) and extend temporally from 1 January 1980 to 31 December 2019 (40 years). Extreme fire danger days were defined based on DSR exceeding the locally (grid cell-specific) defined 95th percentiles (reference period 1981

– 2010). We opted for using percentile-based local thresholds since previous studies have shown that local extremes promote large fire growth (e.g., Abatzoglou et al., 2021).

The statistic used to quantify changes in extreme fire danger occurrence in Europe is the annual count of extreme DSR days. We applied the non-parametric Pettitt test (Pettitt, 1979) to detect abrupt changes in the time series of extreme DSR days, and the non-parametric Mann-Kendall (MK) test (Mann, 1945; Kendall, 1976) to quantify long-term trends. Finally, we supplemented our analysis with observed burnt area data for the 2001 – 2019 period, retrieved from the FireCCI v5.1 dataset (Lizundia-Loiola et al., 2020) of the European Space Agency (ESA) Climate Change Initiative.

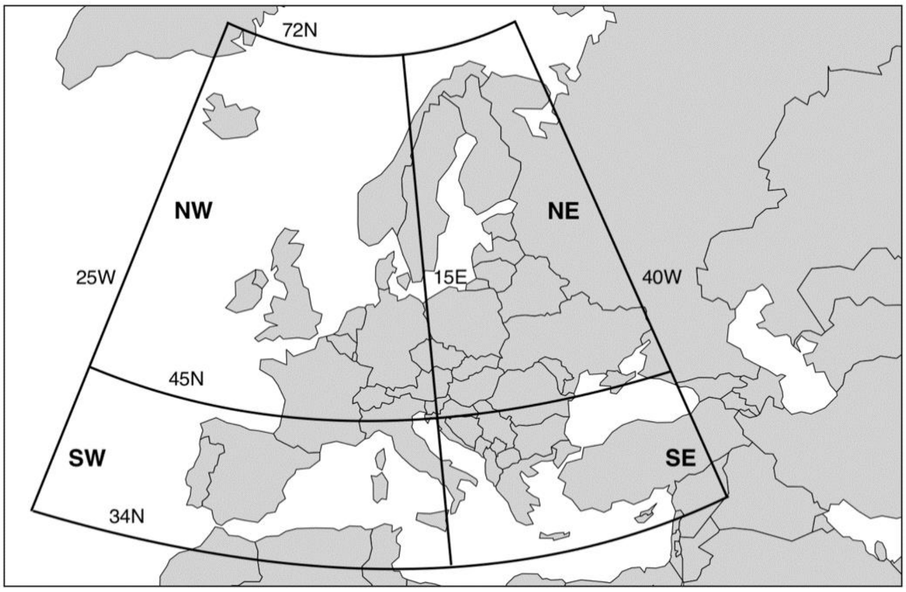

Figure 1 – Study area with identification of the different sub-regions used in the analysis.

3. Results

3.1. Relationship between fire danger and burnt area

Figure 2 summarizes a simple exploratory analysis between the annual count of extreme fire danger days and the annual total burnt area (in non-agricultural vegetation class categories) in the examined sub-regions of Europe (Figure 1). Results indicate a statistically significant ($p < 0.05$) positive relationship between the two variables (Figure 2a), which is stronger in the eastern part of the study area (SE, NE) than in the western part (SW, NW). Further, it can be seen that the most destructive years during the examined period (2001 – 2019) coincide well with peaks in the annual count of extreme fire danger days in all European sub-regions (Figure 2b).

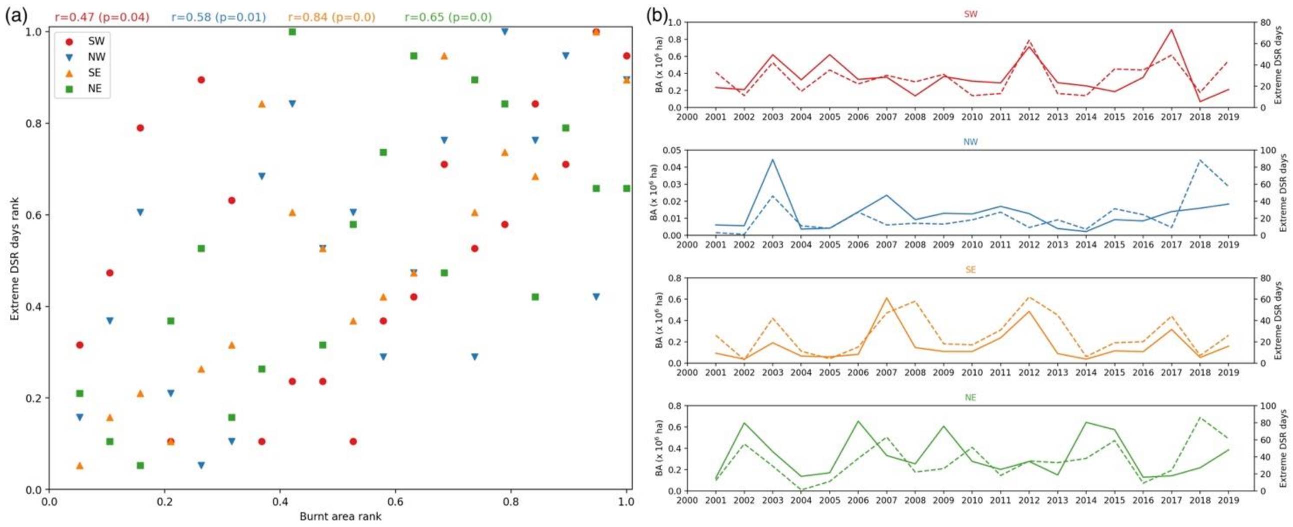

Figure 2 – (a) Scatter plot between the annual total burnt area in the different European sub-regions and the corresponding annual count of extreme DSR days. All data are plotted in their rank order, scaled between 0 and 1. Different colors and symbols are used for the data pooled from the different sub-regions. Spearman correlation coefficients (r) and their associated p-values are shown on top of the plot, with colors corresponding to the different European sub-regions. (b) Time series of the annual total burnt area (solid lines) and the corresponding annual count of extreme DSR days (dashed lines) in the different European sub-regions.

3.2. Seasonality and changes in extreme fire danger occurrence

Extreme fire danger days exhibit a clear seasonal cycle (Figure 3), occurring primarily during the warmest part of the year, from June to September in southern Europe (SW, SE) and from May to September in northern Europe (NW, NE). This suggests that the northern European countries are more prone to experiencing locally extreme fire danger days at the edge of the traditional fire season (May to October) compared to the southern Mediterranean countries, where occurrences of extreme fire danger days peak during the hottest months of July and August.

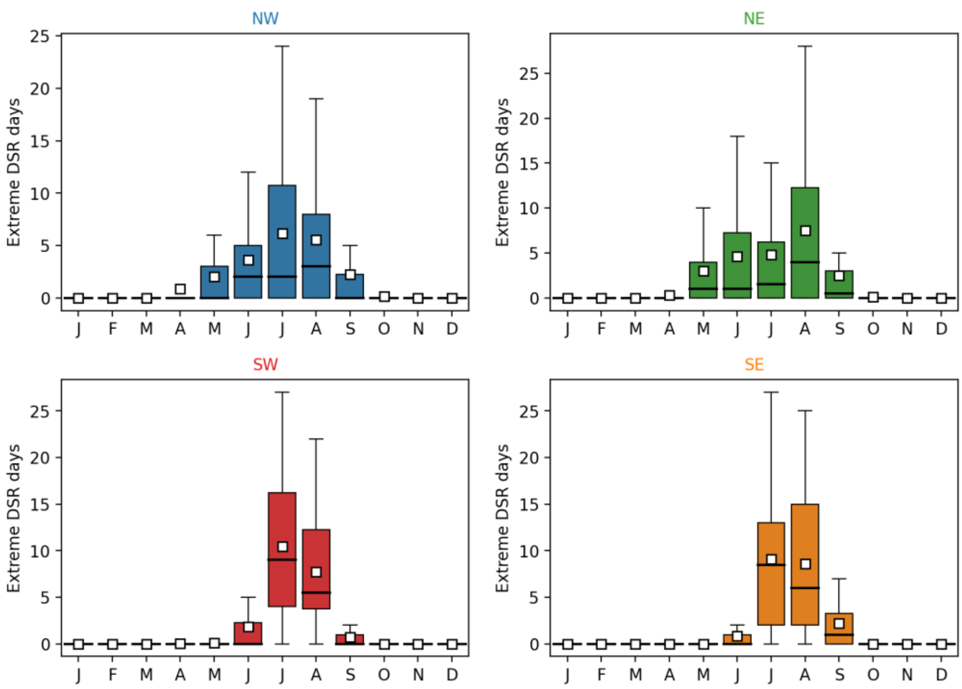

Figure 3 – Monthly distribution of extreme DSR days in the different European sub-regions for the period 1980 – 2019. Solid black lines and white boxes denote median and mean values, respectively. Error bars indicate the interquartile range of the data.

Extreme fire danger days have increased between 1980 and 2019 in all European sub-regions (Table 1). Statistically significant ($p < 0.05$) increases were computed for the SW, SE, and NE sub-regions, whereas a non-significant trend was found in the NW sub-region. The magnitude of the statistically significant increasing trends was found to range from an additional 4 days per decade in the SE sub-region to more than 10 days per decade in the NE sub-region.

Table 1 – Extreme DSR days trends in the different European sub-regions, computed for the 1980 – 2019 period. Show are the decadal trends computed using the MK test and the associated p values.

European sub-region	Trend (days decade^{-1})	p-value
SW	6.3	0.00
NW	3.0	0.23
SE	4.3	0.01
NE	10.9	0.00

Results of the Pettitt test indicate that the increasing occurrences of extreme fire danger days in the SW and NE European sub-regions may be linked to abrupt changes in the means. The change-points for the above two sub-regions occurred in the 1990s (1991 for the NE and 1997 for the SW), marking sharp increases in the mean annual number of extreme fire danger days (Figure 4).

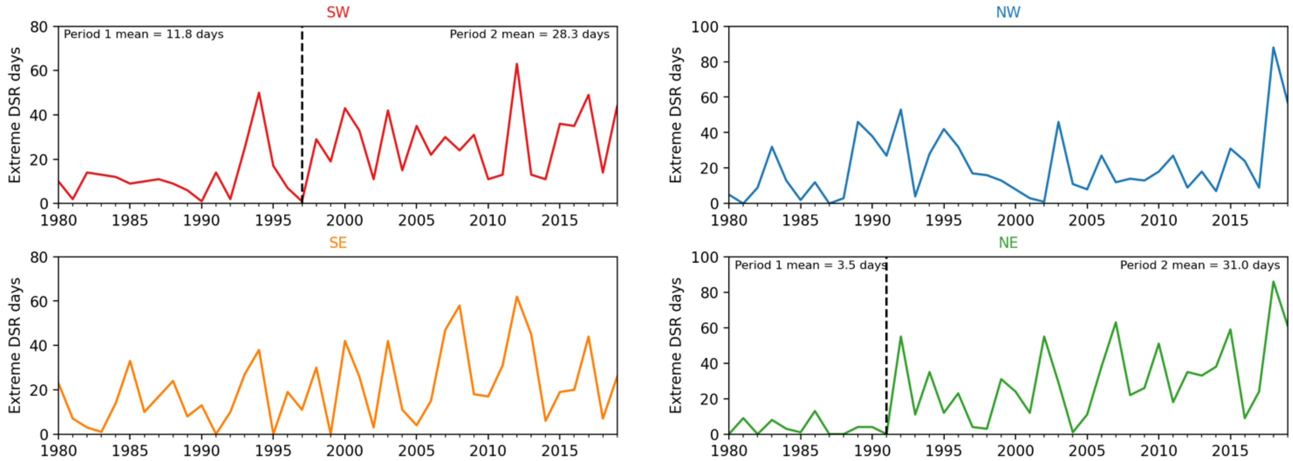

Figure 4 – Time series of the annual count of extreme DSR counts in the different European sub-regions. Vertical dashed lines denote statistically significant potential change-points.

Concerning the spatial variability of changes in extreme fire danger days, Figure 5 reveals widespread, statistically significant potential change-points over a large part of Europe. The largest changes were found in the eastern part of the study area, where many grid cells were found to experience up to more than 30 additional extreme fire danger days per year after the year of the potential change-point (Figure 5b). The related change-points were found to occur mostly in the early 1990s (Figure 5a, green-colored grid cells). Grid cells in south-eastern Spain were also found to experience large increases, up to more than 20 additional extreme fire danger days per year after potential change-points that occurred in the mid-1990s. Finally, grid cells in central Europe (eastern France, southern Germany) were found to exhibit 10 – 15 additional extreme fire danger days per year after potential change-points that occurred in the 2000s.

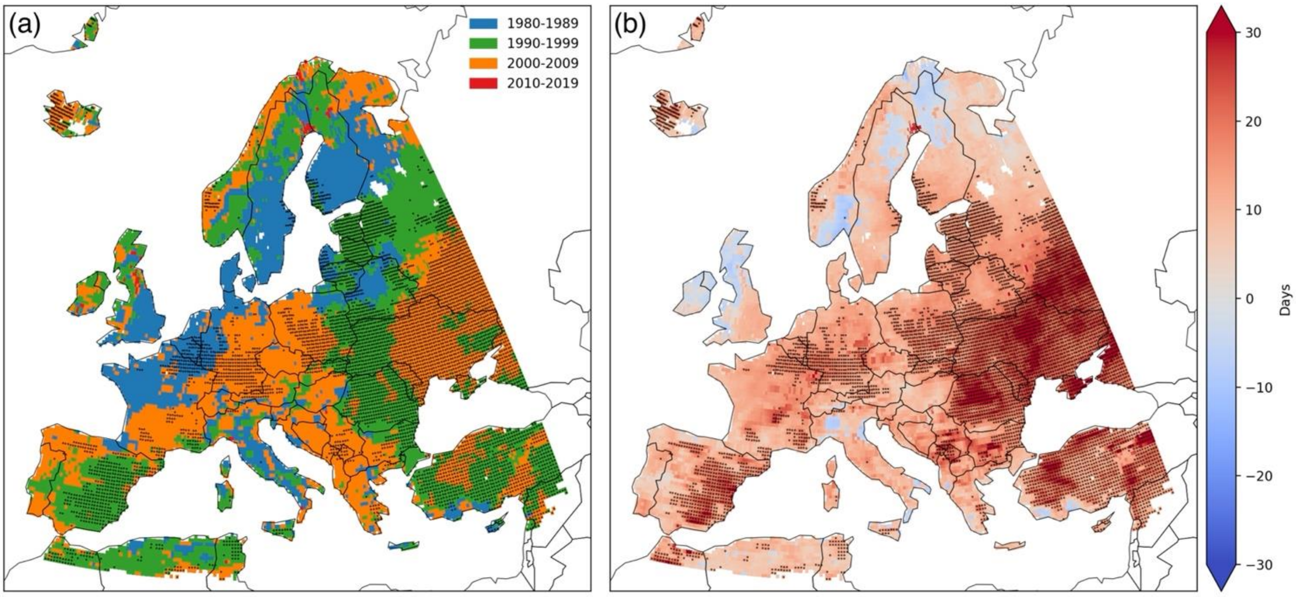

Figure 5 – (a) Years of potential change-points in the time series of the annual count of extreme DSR days. (b) Change in the mean annual count of extreme DSR days before and after the potential change-points. Stippling indicates statistical significance (at the 95 % confidence interval) of the potential change-points. Change points and the associated statistical significance were computed using the non-parametric Pettitt test.

4. Conclusions

The preliminary results of our spatiotemporal analysis indicate that extreme fire danger days have increased in Europe during the period from 1980 to 2019. Within large parts of the SW and NE European sub-regions, but also in central Europe, these increases seem to have taken place abruptly. This conclusion is supported by the statistically significant potential change-points that were identified in the time series of the extreme fire danger days. Abrupt changes appear to have occurred in the mid-1990s in the SW sub-region and over the largest part of the NE sub-region, marking very large changes in the mean annual occurrences of extreme fire danger days before and after the year of change. It can be speculated that these abrupt changes may be associated with changes in large-scale atmospheric circulation and atmospheric teleconnection patterns, which in turn gave rise to increases in temperature and decreases in humidity and precipitation. However, this is an hypothesis that needs to be statistically verified before reaching to robust conclusions.

5. Acknowledgments

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