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Analysis of the Canadian Fire Weather Index during large fires in Croatian Adriatic

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Abstract

Wildland fires, especially the large ones, are becoming a growing problem in the climate-changing world. More frequent and long-lasting drought conditions accompanied by high temperatures and heat waves significantly increase fuel flammability, particularly during summer.

The wildland fire occurrence and behaviour are to a large degree weather driven and thus strongly depend on the meteorological parameters such as humidity, temperature, precipitation, and wind speed as well as on the amount of fuel load. The relationship between weather and fire occurrence and behaviour is included in the Canadian Fire Weather Index System (FWI), which has been used in Croatia for fire risk assessment since 1982.

This paper analyses the characteristics of the Fire Weather Index components for large fires in the Adriatic region of Croatia. Fire weather indices were evaluated for 103 wildland fires with a burned area of over 400 ha that occurred during summer fire seasons from 2003 to 2021. Obtained median values of the moisture indices, as well as the fire behaviour indices (FFMC 93, DMC 139, DC 649, ISI 13, BUI 182 and FWI 45) showed values designated as high and very high in the available literature. Compared to daily frequency distribution of indices for fire seasons from 2003 to 2021, the indices during large fire days belong primarily in their upper percentile categories (>75 percentile).

Climate change will continue to increase the fire risk and thus the possibility of large fires so this analysis can provide a baseline for improvements and recalibration of the fire danger classes in the Adriatic area of Croatia. Along with the improved fire weather warnings, this will give better and more accurate information about the increased wildland fire risk and the possibility of large fires.

1. Introduction

The Mediterranean region is the most prominent climate response hot spot (Giorgi, 2006), and Croatia is no exception. Climate analysis of the last 30 years shows noticeable trends in mean temperature rise and the more frequent occurrence and longer duration of extreme meteorological events such as dry spells and heat waves (Gajić-Čapka et al., 2010). These conditions contribute to the increase of fire risk and lengthening of the fire seasons, which tend to start earlier, in May, and extend until October, sometimes even until November. As a result, meteorological fire weather indices also show a rising trend, indicating a growing risk of large fires.

Weather is one of the main drivers of the wildland fires and the most variable one, both spatially and temporally. Long-lasting droughts and high temperatures provide favourable conditions for ignition by dehydration of fuel, and the wind is one of the main factors of fire propagation. Thus, weather parameters such as temperature, relative humidity, precipitation, and wind speed are considered when assessing the risk and behaviour of wildland fires. The Canadian Fire Weather Index (FWI) and its components - fuel moisture codes (FFMC, DMC and DC) and fire behaviour indices (ISI, BUI) represent the cumulative effect of the weather on fuel and thus allow the assessment of fire risk (Van Wagner, 1987).

For the past 40 years, the Canadian Fire Weather Index System has been used in Croatia for fire risk assessment. The index was calibrated for the Adriatic based on the statistical analysis of the burned area and the number of fires. Also, the fire danger classes were derived through a combination of FWI and BUI (Dimitrov, 1987).

At the peak of the fire season, the fire danger classes are predominantly high and very high. Therefore, they do not provide additional information about the fire risk, especially the conditions favourable for large fires.

2. Method and Data

The study area is the Croatian Adriatic, characterized by the Mediterranean climate. It is covered with agricultural land and Mediterranean vegetation, which are particularly conducive to wildland fires. The area can also be considered the wildland-urban interface zone, with many settlements integrated into the wilderness.

Information on the large fires between 2003 and 2021 was obtained from the Croatian Fire Fighting Association. They contain data about fire location, ignition and extinction date and time, and the total burned area.

In the literature, different thresholds of burned area for large fires can be found. Since the purpose is to evaluate indices for the conditions when the extreme fire spread and erratic fire behaviour were present, the wildland fires with a burned area bigger than 400 ha were referred to as large fires (Heilman and Bian, 2010).

For the analysis, the daily values of the Fire Weather Index components were used, calculated at 12 UTC, for 24 meteorological stations of the Croatian Meteorological and Hydrological Service. The values from the stations closest to the fires were relevant to the investigation and used in the analysis (Figure 1).

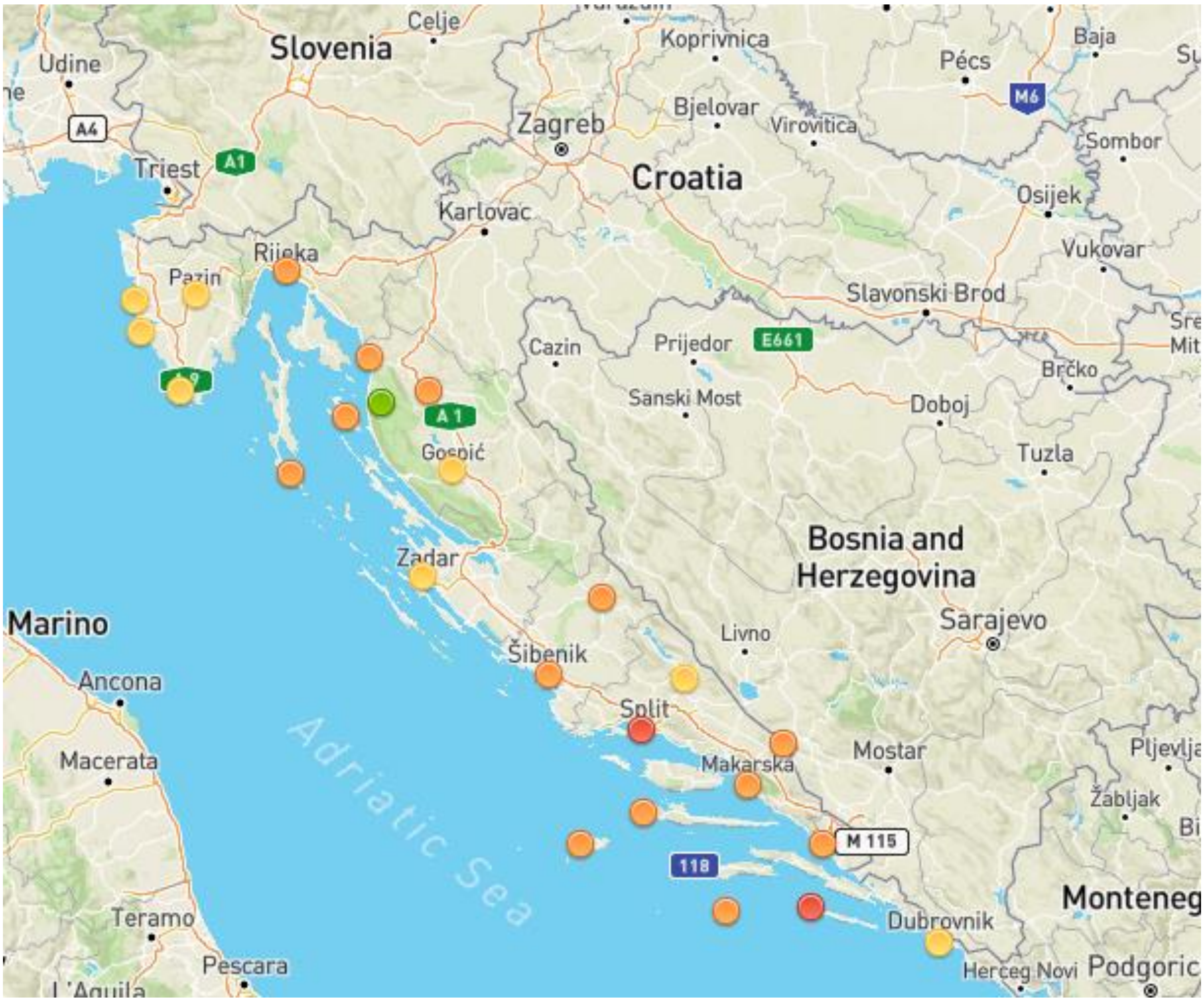


Figure 1 – Location of DHMZ weather stations, source DHMZ.

Empirical cumulative distribution frequency analysis and median and percentile categories were calculated for each FWI component. For comparison, daily distributions of indices for fire seasons (May to September) from 2003 to 2021 were also calculated. The objective of the analysis was to obtain estimates of the index values commonly present during the large wildland fires.

3. Results and Discussion

Statistics for each FWI component is given in Table 1, which summarises the median and percentiles (10, 25, 75 and 90) for FFMC, DMC, DC, BUI, ISI and FWI for days with large fires and fire seasons for a period from 2003 to 2021. Additionally, minimum and maximum values and average and standard deviation are displayed. Related cumulative frequency distributions are shown in Figures 2 to 7.

Table 1 - Statistical values for FWI components (median and percentiles, minimum and maximum value, average and standard deviation) for large fires and daily distribution for fire seasons from 2003 to 2021.

Parameters	**Percentiles**					**Min**	**Max**	**Average**	**Standard deviaton**
	10	**25**	**Median**	**75**	**90**				
FFMC large fires	88	90	93	94	96	73	98	92	3.8
daily distribution	72	85	89	91	93	4.1	98	85	11
DMC large fires	86.4	110	139	184.5	233.2	40	367	150.3	56.4
daily distribution	14.8	28.8	55.8	94.7	143.5	0.4	454.8	70	56.1
DC large fires	487	552.5	649	783.5	874	106	986	662.8	153.2
daily distribution	86.5	174.6	335.7	515.3	681	3.8	1138.7	361	225.1
ISI large fires	6	9	13	19	24.6	1	55	14.6	8.2
daily distribution	1.3	3.9	6.7	10.3	15.2	0	115.2	7.9	6.4
BUI large fires	125	146	182	221.5	262	66	367	187.5	53.2
daily distribution	21.2	40.1	75.5	122.8	176	0.7	454.7	89.2	63.8
FWI large fires	26	34	45	57	67.6	6	108	46	17.2
daily distribution	2.6	10.2	20.7	32.1	44	0	166.5	22.6	16.3

3.1. Fine Fuel Moisture Code – FFMC

The median of FFMC during large fires has a relatively high value of 93, as shown in Table 1. 10-90th percentile interval indicates closely clustered data around the median, with 50% of FFMC values for large fires between 90 and 94, situated above daily frequency median (89).

The FFMC is a numeric rating of the moisture content of fine fuels on forest surface and an indicator of ease of ignition (Van Wagner, 1987). Small spread around the mean as well as the steep slope of both cumulative frequency distributions (Figure 2) point to very low moisture content in fine fuels during most of the days, which can be expected in summer, especially in the environment favourable for large fires. An FFMC of 92 or more points to a high probability of the onset of extreme fire behaviour, depending on the wind and BUI level (Alexander and Cole, 2001). According to the FFMC analysis, these values have been observed in the 50% of large fire data set, and only in 10% of daily distribution (Figure 2).

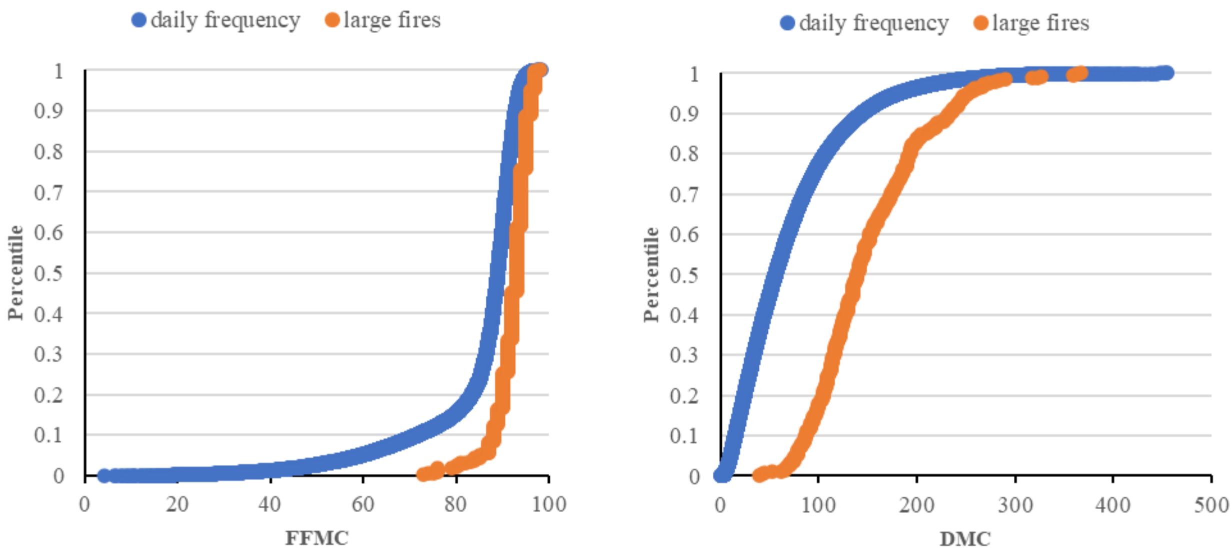


Figure 2 and 3 - Cumulative distribution of Fine Fuel Moisture Code (FFMC) and Duff Moisture Code (DMC) for large fires (red) and daily distribution (blue)

3.2. Duff Moisture Code - DMC

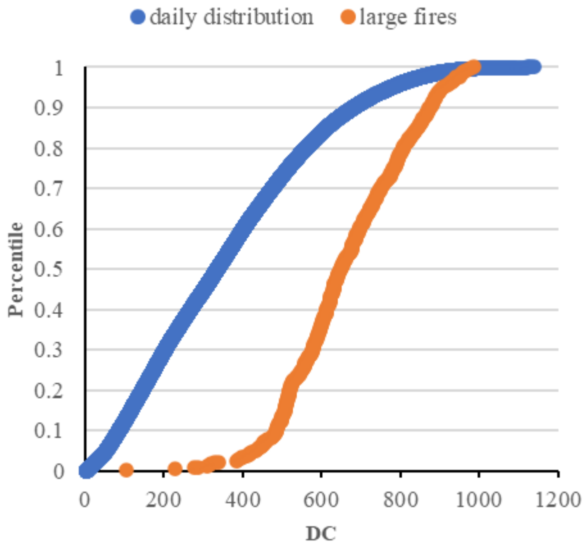
The cumulative frequency analysis for the DMC (Figure 3) shows a median of 139 for large fires and a significantly lower value of 56 for daily distribution (Table 1). Most large fire values are higher than the daily median.

The DMC indicates fuel consumption in moderate duff layers and medium-size woody material, and a value of 150 to 200 indicates that the duff will have lost most of its moisture (Van Wagner, 1987, Canadian Forest Service, 1996). While this is the case in 43% of large fire values, only 10% of daily distribution values indicates moisture loss in duff layers. The DMC analysis could suggest that large wildland fires in the Adriatic occurred even in cases of duff layers not completely dried out.

3.3. Drought Code - DC

According to percentile values (Table 1), for most days with large fires, the DC index was between 487 and 874, with a median of around 650. This value range is situated in the upper 70% of daily distribution values. However, the daily median is much lower, around 335.

The DC index is a numeric rating of the moisture content of a deep layer of organic matter (Van Wagner, 1987) and an indicator of seasonal drought. At a value of 300, the moisture content starts to decrease with depth (De Groot, 1987), so 99% of DC data (Figure 4) show drought conditions were present during large wildland fires, while 55% of daily values were above 300.



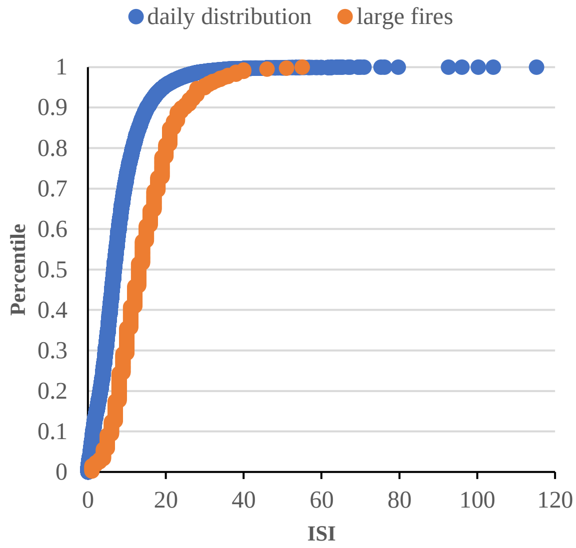


Figure 3 and 4 - Cumulative distribution of Drought Code (DC) and Initial Spread Index (ISI) for large fires (red) and daily distribution (blue)

3.4. Initial Spread Index - ISI

ISI for large fires showed a much larger spread around the median than other indices (Table 1, Figure 4), which is understandable considering its dependence on wind speed. The median for large fires was around 13, with data ranging mostly from 6 to relatively high 25, values that correspond to the 10th and 90th percentile. Compared to daily distribution, about 80% of large fire values were higher than the daily distribution mean. The highest ISI value for large fires was 55, while from 2003 to 2021, values up to 115 were recorded.

Combining the effects of wind and FFMC, the ISI is a numeric rating of the expected rate of fire spread (Van Wagner, 1987). The ISI is used in association with the BUI (or with the degree of curing, in the case of grass fuel types) in the FBP System (Forestry Canada Fire Danger Group 1992) to provide numeric values for fire behaviour for predetermined forest and slash fuel types.

3.5. Buildup Index - BUI

According to the cumulative frequency, BUI mean for large fires (Figure 6, Table 1) is 182, while 90% of the values (125 to 262) are above the 75th percentile of the daily distribution.

The BUI index is a numeric rating of the amount of fuel available for combustion (Van Wagner, 1987) and represents the fire potential. The statistical analysis done by Dimitrov (1987), currently used for fire danger assessment, classified BUI values as very low (0-48), low (49-85), moderate (86-118), high (119-158) and very high (159+). Therefore, around 70% of the large fire values and less than 15% of daily distribution can be placed in very high Dimitrov's class.

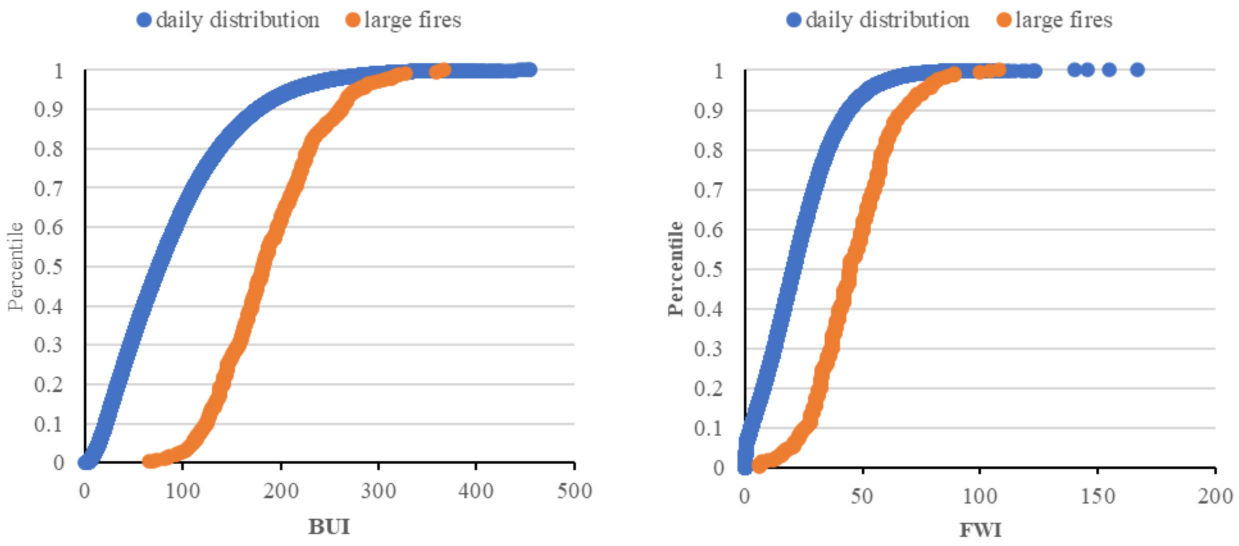


Figure 6 and 7 - Cumulative distribution of Buildup Index (BUI) and Fire Weather Index (FWI) for large fires (red) and daily distribution (blue)

3.6. Fire Weather Index - FWI

Analysis shows that 80% of FWI values for the large fires, ranging between 26 and 68 (Table 1, Figure 7), are situated above the daily frequency median (21). The large fire median of 45 is above the 90th percentile of the daily distribution.

The FWI is a general index of fire danger and a numeric rating of fire intensity calculated from ISI and BUI (Van Wagner, 1987). The FWI values used in Croatia, according to Dimitrov (1987), are considered very low (less than 4), low (5-8), moderate (9-16), high (17-32) and very high (33+). The 25th percentile of the large fire distribution is on the lower boundary of the very high Dimitrov's class, meaning that 75% of FWI data fall in the very high fire danger class.

4. Conclusion

Climate change scenarios suggest extreme weather events such as long dry periods and heatwaves will be more frequent and stronger in the future (Branković et al., 2012). As a result, the conditions conducive to fire will be more common in Croatia, particularly on the Adriatic.

The analysis of the FWI indices during large wildland fires provides an insight into the range of values that typically appear when weather conditions are favourable for extreme fire spread and behaviour. Median values of indices (FFMC 93, DMC 139, DC 649, ISI 13, BUI 182 and FWI 45) showed values designated as high and very high in the cited literature, particularly in Dimitrov (1982), and generally fall in the upper percentile categories (> 75th percentile) of daily frequency distribution for fire seasons from 2003 to 2021. Moreover, 70% of BUI and 75% of FWI fall into the very high Dimitrov's class. So, the median values and upper percentiles, e.g., 90th obtained for large fires and fire weather warnings, can be used as additional information for forecasters and fire managers when assessing the possibility of large fire occurrence.

The climatology of the FWI indices for the Adriatic is long overdue, along with the new calibration of the Index. Dimitrov's fire danger classes have proven inadequate during the peak of fire season when values are predominantly high and very high. However, there are some efforts to calculate the most recent climatology. Results obtained in this paper together with the new FWI climatology could provide a baseline for recalibration of the fire danger classes.

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