ADVANCES IN FOREST FIRE RESEARCH

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Fire Weather Warnings in Croatia

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Abstract

Vegetation fires are among the most dangerous natural hazards. In Croatia, they are most common on the Adriatic coast and in the areas near the Adriatic, especially in summer when the peak of the fire season occurs. Meteorological risk of vegetation fires in Croatia is primarily assessed with the Canadian Forest Fire Weather Index and derived fire danger. However, due to the rare spatial and temporal availability of these data as well as the effects of climate change resulting in frequent enhanced fire danger during the summer, the need for additional risk assessment tool has emerged. In that sense, the fire weather warnings were introduced ten years ago and since then have been constantly improved and adapted to the needs of the firefighting community. The aim is to warn of weather conditions that can lead to the rapid spread and unpredictable behavior of the vegetation fires. As a basic condition, fire weather warnings are issued when the fire danger classes from the Canadian Forest Fire Weather Index are high and very high. Except the meteorological parameters of the Fire Weather Index, the most important of which is wind, the behavior and spread of vegetation fires can be further influenced by atmospheric turbulence and instability in the dry air near the ground and in the lower atmosphere. These parameters also depend on the orography of the terrain and are not included in the Fire Weather Index. Two years ago, three levels of warnings were defined, the thresholds of which depend on the values and duration of wind, turbulence and instability. In addition to the detailed explanation of the method for issuing fire weather warnings, the paper presents textual and graphical warning examples, describes five critical fire weather patterns when conditions for issuing warning are the most common, and in the end gives a brief overview of warnings statistics and the most recent evaluation. According to the feedback from the firefighting community, the warnings proved to be important in the organization of supervisory and preventive activities, as well as fire suppression activities in case of vegetation fire ignition. The evaluation also shows that most of the significant vegetation fires burned in the days and at the locations for which warnings were issued.

1. Introduction

Vegetation fires belong to the most dangerous natural hazards and are closely related to weather and climate. As official institution in Croatia that deals with dangerous weather and weather-related hazards, Croatian Meteorological and Hydrological Service (DHMZ) is responsible for issuing forecasts and warnings on such phenomena. DHMZ cooperates with the Civil Protection Directorate, the Ministry of Defence and the Croatian Firefighting Association - organisations participating in the protection and rescue of people and property.

In Croatia vegetation fires are most common in the warm part of the year on the Adriatic coast and in the areas near the coast with the peak of fire season in the summer months. Therefore, fire protection and related activities are conducted mostly from spring to autumn, usually from May to October. In the fire protection system DHMZ is acting as advisory body, providing specialized meteorological information to the stakeholders of the system, primarily Croatian Firefighting Association (Kozarić et al., 2015).

The assessment of meteorological risk of vegetation fires is primarily based on the Canadian Forest Fire Weather Index (FWI) system, described in Van Wagner C.E. (1987), and on the fire danger classes calculated from the FWI. The analysis and forecasts of these data are unfortunately rarely available, only once a day at 24 meteorological stations. Climatological analysis shows that since 1990s the mean temperature in Croatia has been increasing with prominent positive trend as well as the extreme meteorological events, such as long dry spells and heat waves, particularly in the Adriatic area (Gajić-Čapka et al., 2010). This climate change consequently affects Fire Weather Index which shows positive trend as well, while at the same time, the fire

danger clasess tend to exibit prolonged periods of the highest values during the peak of fire season in summer. On the other hand, FWI does not include information on wind shear or change in direction. For this reasons a need for additional risk assessment tool has emerged and led to the development of the fire weather warnings. They were introduced ten years ago and since then have been constantly improved and adapted to the needs of the firefighting community. Basically, its purpose is to warn of weather conditions that can lead to the rapid spread and unpredictable behavior of the vegetation fires.

2. Method

As a basic condition, the fire weather warnings use the fire danger classes calculated from the Forest Fire Weather Index. A definition of classes is described in Dimitrov (1987) and shown in Table 1. Fire danger classes account for the total amount of fuel available for combustion, represented as the Buildup Index (BUI), and the relevant meteorological parameters included in FWI, the most important of which is wind speed. In terms of fire danger, classes have been assigned the following values: 1-very low, 2-low, 3-moderate, 4-high, and 5-very high. FWI represents the expected intensity of the spreading fire.

Table 1 - Fire danger classes calculated by combining FWI and BUI. Color is assigned to each class.

		Fire Weather Index (FWI)				
		0-4	5-8	9-16	17-32	33+
Buildup Index (BUI)	0-48	1	2	2	3	3
	49-85	2	2	3	3	4
	86-118	2	3	3	4	4
	119-158	2	3	4	4	5
	159+	3	3	4	5	5

The spread rate and the erratic, unpredictable behavior of wildland fires can be strongly increased by the atmospheric turbulence (Heilman and Bian, 2010) and the instability in a dry air (Haines, 1988), both near the ground or in the atmospheric boundary layer. Atmospheric turbulence is most often represented by turbulent kinetic energy (TKE) and instability in dry air by the Haines Index (HI). TKE takes into account an increased influence of orography on the wind, particularly causing gustiness and shear which are not included in the FWI. The highest values of HI are generally coincident with the large burned area and increased number of forest fires which is also the case in the Adriatic region of Croatia (Kozarić and Mokorić, 2014).

Two years ago, three levels of warnings were defined, i.e., yellow, orange, and red, allowing more precise distinction between dangerous weather conditions. The thresholds for levels depend on the values and duration of the three important meteorological parameters – wind speed, TKE and HI. Typically, red warning alerts of the most dangerous fire weather conditions. The latest improvements and adaptation of the fire weather warnings done in 2021 will be explained.

The criteria for fire weather warnings are given in Table 2. Meteorological parameters and fire danger classes are placed in rows of the table. Threshold values for these are in the cells of table columns.

Table 2 - The criteria for fire weather warnings. First condition is monitored in the first row, second condition in the rows 2 to 4.

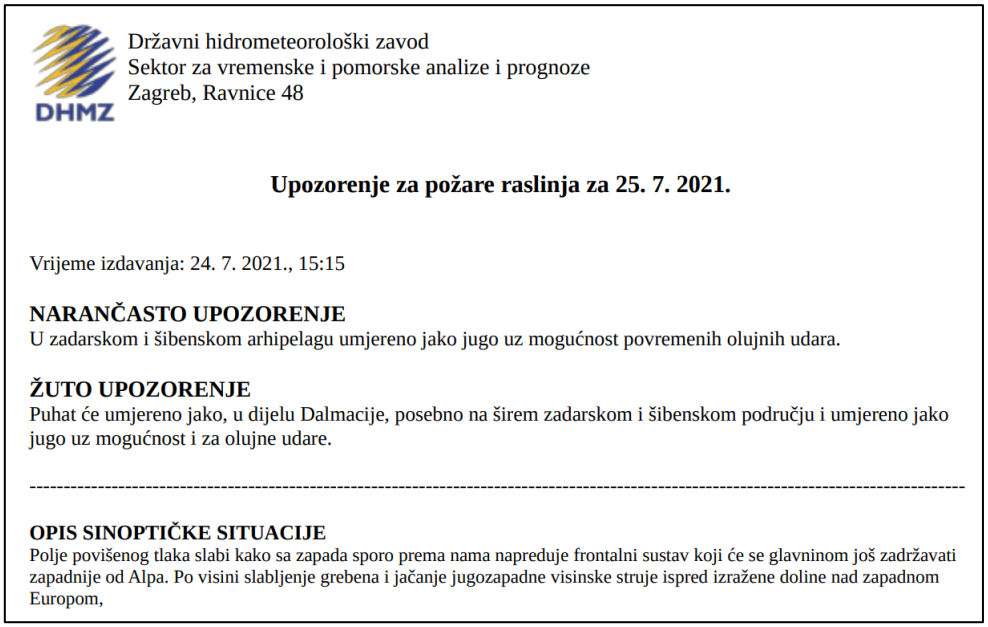
	Warning level			
	Yellow		Orange	Red
Fire danger class	Moderate	High and/or very high	High and/or very high	High and/or very high
Wind speed (ms^{-1})	>9 (5 hrs or more)	6 to 9 (5 hrs or more)	>9 (2-3 hrs or more)	>9 (18 hrs or more)
TKE (m^2s^{-2})		3 to 5 (5 hrs or more)	>5 (2-3 hrs or more)	>5 (18 hrs or more)
HI		6 (5 hrs or more)		

First condition to be monitored by the DHMZ's forecasters is the fire danger class which should be high and/or very high indicating increased dryness of the fuels. These values tend to be present in most days during peak of the fire season in the Adriatic, particularly in the south. As already mentioned, fire danger classes data are calculated at 24 locations at 12 UTC every day, either as analysis or forecast for next day. It is supposed that classes at 12 UTC represent fire danger for the whole day. Moderate fire danger class is also relevant but only in cases of particularly strong wind lasting for prolonged time.

Second condition to be monitored are the values of parameters of wind speed, TKE and HI, and a duration when exceeding the threshold values in the certain area. These data are available as model fields from numerical weather prediction (NWP) models, e.g., mostly used is in-house mesoscale model ALADIN (Tudor et al., 2016).

If values of at least one meteorological parameter, i.e., wind speed, TKE or HI, or any of their combinations meet the second condition and overlap with the first condition, the warning level is defined. For example, condition for yellow warning will be met if the fire danger class is very high and TKE in the area is from 3 to 5 m^2s^{-2} for 5 or more hours. Special maps in our workstation system have been developed to help forecasters in making these decisions. Note, Haines Index of the highest value 6, can only contribute to yellow warning. According to Croatian firefighters' feedback wind-driven fires cause major problems and the influence of instability (HI) was agreed to be reduced in the alerting process.

In accordance with the criteria, fire weather warnings are produced daily from the beginning of May to the end of October and issued to firefighting community as textual (Figure 1) and graphical product (Figure 2). Warnings are produced separately for the current day, using the analysis of fire danger classes, and for the next day using the forecasted fire danger classes as a first condition. In addition to the warning levels descriptions, a large-scale weather pattern description is included in the textual product.



Državni hidrometeorološki zavod
Sektor za vremenske i pomorske analize i prognoze
Zagreb, Ravnice 48

Upozorenje za požare raslinja za 25. 7. 2021.

Vrijeme izdavanja: 24. 7. 2021., 15:15

NARANČASTO UPOZORENJE
U zadarskom i šibenskom arhipelagu umjereno jako jugo uz mogućnost povremenih olujnih udara.

ŽUTO UPOZORENJE
Puhat će umjereno jako, u dijelu Dalmacije, posebno na širem zadarskom i šibenskom području i umjereno jako jugo uz mogućnost i za olujne udare.

OPIS SINOPTIČKE SITUACIJE
Polje povišenog tlaka slabi kako sa zapada sporo prema nama napreduje frontalni sustav koji će se glavninom još zadržavati zapadnije od Alpa. Po visini slabljenje grebena i jačanje jugozapadne visinske struje ispred izražene doline nad zapadnom Europom,

Figure 1 - An example of the textual fire weather warning product (in Croatian). List of warnings sorted by the level is followed by the large-scale weather pattern description.

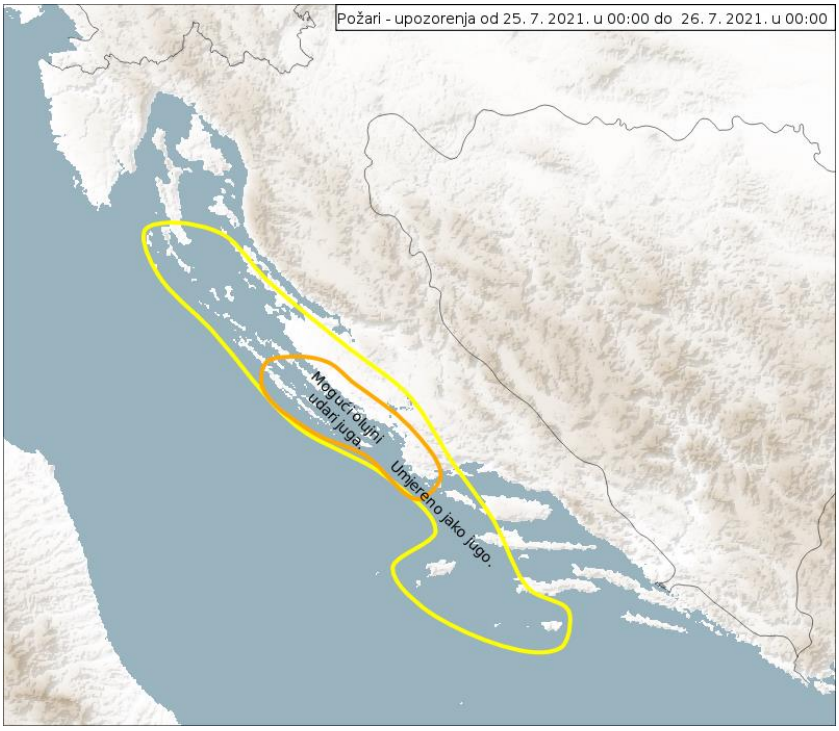


Figure 2 - An example of the graphical fire weather warning corresponding to the textual one (also in Croatian).

3. Critical fire weather patterns

This section describes five critical fire weather patterns when conditions for issuing warnings were most common. These large-scale patterns have been determined by the analysis of synoptic weather situation over Europe, both at surface and aloft, in the days when fire weather warnings were issued due to increased values of meteorological parameters (Mokorić and Hojsak, 2018).

- Pattern 1. Cold front passage followed by high pressure ridge strengthening from the North-west. Usually lasts a few days accompanied by enhanced northeasterly gusty downslope wind, called "Bura", turning to moderate to strong northwesterly wind.
- Pattern 2. Cold front passage with little or no rain ("dry" cold front) and gusty variable winds.
- Pattern 3. Situation of medium or slightly higher air pressure filed, usually non-gradient, accompanied by the instability in dry air (high values of the HI). Usually lasts for several days.
- Pattern 4. Enhanced southeasterly wind (called "Jugo") without rain, prior to approaching cold front.
- Pattern 5. The anticyclonic ridge that extends from northern Europe towards the Adriatic. Often lasts for a few days accompanied by enhanced "Bura".

There are some indications that the annual frequency of these patterns has been increasing in the last ten years, however this has to be explored more thoroughly.

4. Statistics and evaluation of fire weather warnings

Fire weather warnings in Croatia were first introduced in 2012 and since then have undergone changes in terms of improvements and adaptations. In Figure 3 an overview of warnings statistics is presented. It can be seen that in the last ten years the number of days with warnings was gradually increasing. The positive trend in the number of warning days seems to coincide with the positive trend in the fire danger, what can be addressed to the climate change. A notable jump in the last two years in the number of warning days is partly a result of the use of three-level warning method.

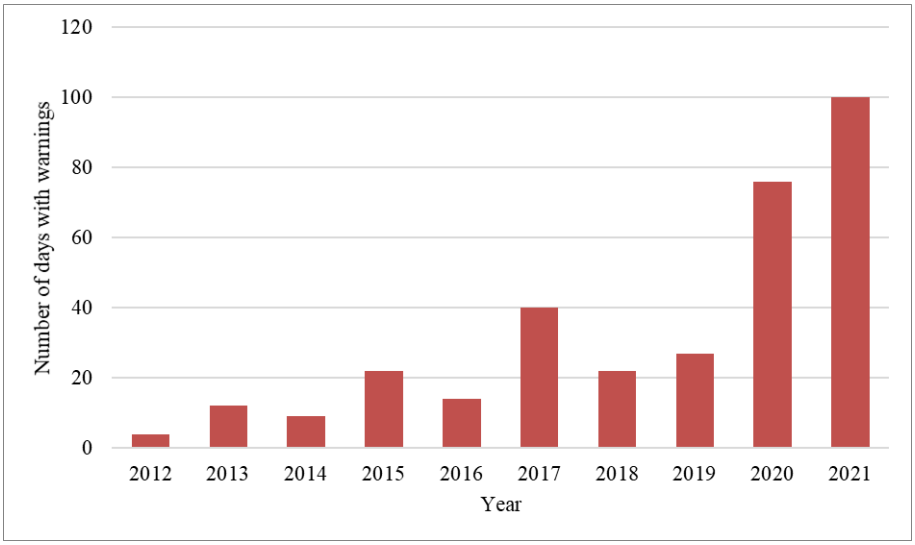


Figure 3 - The number of warning days per fire season in the period from 2012 to 2021.

In order to investigate a possible benefit of fire weather warnings, a simple evaluation was performed with the most recent data from 2021. Forty five days with the significant vegetation fires, i.e., which were hard to suppress or had large burnt area according to reports, were compared with 100 days with issued warnings during fire season. It has to be noted that every warning day is included, no matter how small the warning area was or how short it lasted. With the more strict filtering in terms of coverage and duration of fires, the number of warning days could be reduced significantly, however this was not intention. Furthermore, for the purpose of evaluation only days with the fire occurrence were considered since warnings have not been designed as an indicator of the fire ignition, rather as the indicator of possibility for rapid fire spread and unpredictable behavior. With those restrictions, for 31 out of 45 of the fire days warnings were correctly issued (Figure 4). In case of bigger fires, e.g., 100 ha or more, 7 fire days were covered by the warning and 3 were missed.

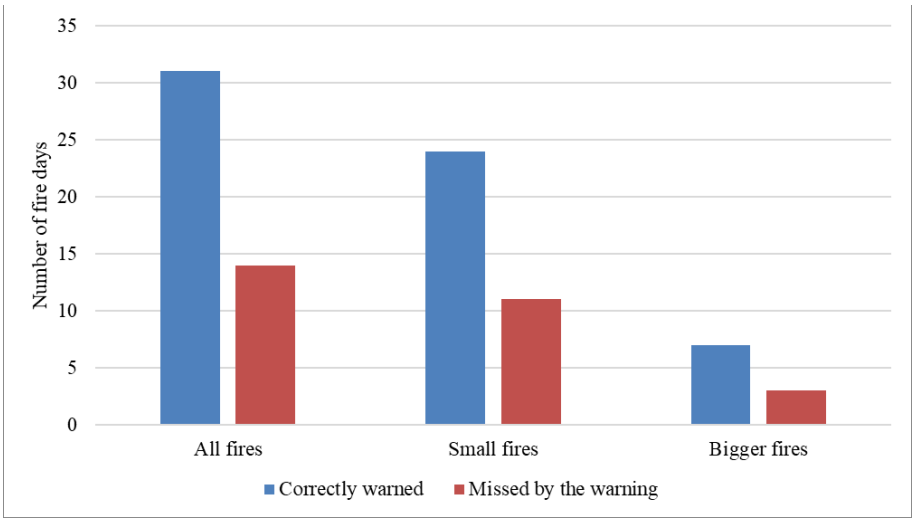


Figure 4 - A simple evaluation of fire weather warnings in the fire season 2021 in case of occurrence of vegetation fires, small and bigger ones. Correctly warned fire days are in blue, missed by the warning are in red.

5. Conclusion

Fire weather warnings in Croatia have been designed to reduce limitations of the assessment of meteorological risk of vegetation fires using only Canadian Fire Weather Index. The limitations are caused by the climate change, poor data availability and the lack of specific meteorological parameters in the FWI, i.e., turbulence and instability.

The main purpose of warnings is to alert to the weather conditions that can lead to rapid spread and unpredictable fire behavior. They are not necessarily an indicator of the fire ignition. The method for issuing is relatively simple, based on predefined criteria, improved over time, and tailored primarily to the needs of firefighting community.

Five critical fire weather patterns have been determined to cause weather conditions favorable for issuing fire weather warnings in Croatia. Most of them are related to strong and gusty wind.

The evaluation showed that most of the significant vegetation fires burned in the days and at the locations for which fire weather warnings were issued. More importantly, according to the feedback from the firefighting community, the warnings have proved to be very useful in the organization of supervisory, preventive and suppression activities.

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