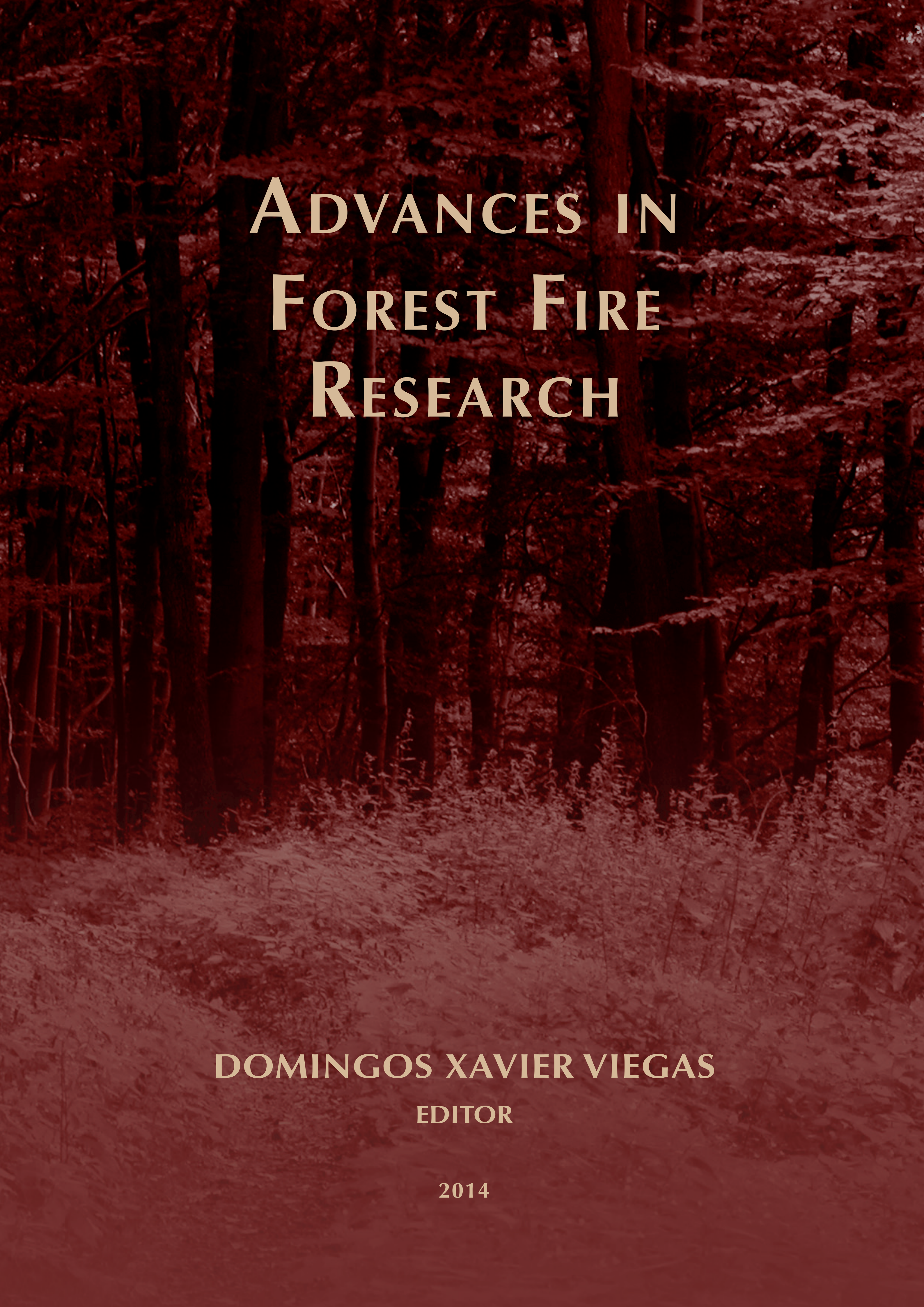

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Haines Index and the forest fires in the Adriatic region of Croatia

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Abstract

It is known that the weather conditions can greatly affect the frequency of forest fires and their behaviour and thus the size of the burned area. Besides the wind, the instability of the atmosphere also affects the fire behaviour and that kind of fires are called "plume dominated". In the dry and unstable atmospheric environment fires are intensified and may behave abnormally. As a quantitative measure of the instability in the dry atmosphere and potential for large fire growth Haines Index is used. Higher value of Haines Index (or the class) means higher potential for fire growth. In this work performance of Haines Index was tested for the Adriatic area, part of Croatia with Mediterranean climate where forest fires are the most common and severe. The distribution of the low-elevation Haines Index calculated from upper air soundings was analyzed as well as relationship between Haines Index and forest fire number and burned area. Analysis was done particularly for Zadar region in summer fire seasons of 2011, 2012 and 2013. In all seasons the smallest percentage of high class of Haines Index was noticed, proportion which was desirable and expected. Surprise was a large proportion of moderate class, which stands out in comparison to the other classes. This result disagreed to the Haines Index statistics found in the literature. However, results showed an obvious connection between Haines Index and forest fires in Adriatic region, particularly Zadar area. In the majority of days of fire seasons the increase of class of Haines Index was related to the increase of number of fires and larger burned area. On average the largest number of fires and largest burned area were associated with the high class. The impact of high class of Haines Index to fire behaviour was pointed out the most when the three-day moving sums/averages were applied. Conclusion is that Haines Index can be used also in the Adriatic region of Croatia as an additional tool for issuing warnings on severe fire weather related to instability. However, there is some place for improvements and further research.

Keywords: *Adriatic, atmospheric instability, forest fire, Haines Index*

1. Introduction

It is known that the weather conditions can greatly affect the frequency of forest fires, their behaviour and thus the size of the burned area.

The instability of the atmosphere, besides the wind, also strongly affects the fire behaviour by generating covective plumes (columns). Forest fires are then denoted "plume dominated". In dry and very unstable atmosphere this kind of fires are intense due to development of stong indrafts with more oxygen entraining from the surrounding environment. Also they may behave abnormally showing high rates of spread, extensive spotting, crowning etc. As a quantitative measure of the instability of the dry atmosphere Haines Index is used.

In this work the performance of Haines Index was tested for the Adriatic area, part of Croatia with Mediterranean climate where forest fires are the most common and severe. Haines Index in Croatia has been used operationally since 2011.

The distribution of the Haines Index calculated from upper air soundings data at Zadar station was analyzed as well as its relationship with the forest fires in the surrounding area during the summer fire seasons.

2. Methods

The summer forest fire season in Croatia typically lasts from the beginning of June to the end of September. Fire seasons in 2011, 2012 and 2013 were considered and during this period all available forest fire data in the Zadar area were collected and analyzed. Also Haines Index data from the Zadar upper air soundings were calculated for the same period.

2.1. Haines Index

Haines Index is a simple index that is based on the vertical lapse rate in some layer of air as well as on moisture content in that layer as described by Haines (1988).
Haines Index is calculated from empirical relation:

$$\mathbf{HI=A(}T_p\text{-}T_{p1}\mathbf{)+B(}T_p\text{-}Td_p\mathbf{)},$$

where A is a function of temperature difference (lapse rate) between the levels of the atmospheric pressure p and $p1$ and B is a function of a dewpoint depression at the level of pressure p. Haines Index is, therefore, the simple sum of stability term (A) and moisture term (B).
Because of the difference in altitudes of certain areas, three elevation variants of Haines Index are calculated: low variant (elevations below 500 m.a.s.l.), middle variant (elevations from 500 to 1500 m.a.s.l.) and high variant (elevations above 1500 m.a.s.l.). The layers p and $p1$ are chosen considering ground elevation and also high enough above the ground to ignore the daily variability of surface temperature and surface temperature inversions. Depending on the upper level atmospheric conditions terms A and B may get values 1, 2, or 3 for each of the variants (Table 1), so Haines Index values between 2 and 6. Lower values are in thermally stable and more humid air and higher values in thermally unstable and drier air.

Table 1. Three elevation variants of Haines Index depending on the terrain elevation and upper level atmospheric conditions, i.e. lapse rate and dewpoint depression.

Lapse rate T_p-T_{p1}			
A	Low 950 - 850 hPa	Middle 850 - 700 hPa	High 700 - 500 hPa
1 2 3	<4 4 to 8 >=8	<6 6 to 11 >=11	<18 17 to 22 >=22
Dewpoint depression T_p-Td_p			
B	Low 850 hPa	Middle 850 hPa	High 700 hPa
1 2 3	<6 6 to 10 >=10	<6 6 to 13 >=13	<15 15 to 21 >=21

The relationship between Haines Index and potential for large forest fires growth or unpredictable behaviour is shown in Table 2.

Table 2. Classes of Haines Index. Values 2 and 3 of Haines Index are combined together in one class (very low).

Haines Index	Class (potential for large fire growth)
2 or 3	very low
4	low
5	moderate
6	high

Generally, Haines Index is designed in the way that low classes are expected most often and accompanied by low potential for large fire growth, while high class is expected rarely but accompanied by high potential for large fire growth. Some additional research on Haines Index can be found in Werth and Ochoa (1993).

In a preliminary analysis conducted in this work the low-elevation variant Haines Index was used because Zadar area has elevation mostly lower than 500 m.a.s.l. (higher mountains occupy smaller part in the north of the region). At this stage possibility of using a middle-elevation variant Haines Index for Zadar area was left for further examination.

Distribution of Haines Index, i.e. percentage of days of the fire season with different Haines Index values, and missing data were calculated for a whole range of soundings and separately for those at 00 and 12 UTC. Analysis is made for all three fire seasons and 122 days per season were taken into account. Also the analysis of stability and moisture terms was performed in the same way to investigate how the values of A and B were distributed and which of them contributed the most.

2.2. **Forest fires and Haines Index**

The available data on forest fires contained information about the location, date, starting time and duration of the fire and the size of burned area. Fire locations were chosen to be less than 100 km away from the station in Zadar. In that case upper air soundings were supposed to be valid for all chosen locations. The proximity condition was satisfied by the total of 930 forest fire cases in 244 days corresponding 21489 hectares of burned area (356 fires in 91days of the fire season 2011 wasted 6369 ha of vegetation, 402 fires in 88 days of fire season 2012 wasted 13206 ha and 172 fires in 65 days of fire season 2013 wasted 1914 ha). In the whole analyzed period there was no significant wind over the area of interest, so all forest fires cases were taken into consideration. It was considered also that a large number of this fires were “plume dominated”, i.e. under the strong influence of the atmospheric instability. For fires lasting more than 2 days burned area was reduced by linear interpolation to the size which might burn in the first 36 hours. This time period was chosen arbitrarily but reasonably so that the reduced burned area could be associated with the Haines Index on the day of the occurrence of fire. Also different truncation times were tested but results showed no significant differences. However, it should be noted that there were just 16 long-lasting forest fires but the idea was not to exclude them.

The relationship between the number of fires in one day and the associated Haines Index at 00 and 12 UTC of the same day was analyzed using box plot statistical method, as well as relationship between total area burned in those fires and Haines Index. Days with missing Haines Index data were omitted. Identical procedure was done with moving sums of number and burned area of fires and the associated moving averages of Haines Index. The idea was not just to test the impact of atmospheric instability on forest fires in one day, but also to see how longer periods with unstable dry weather conditions impact forest fires. Different time (day) windows were used, but three-day forward oriented window seemed to be appropriate for moving sums and averages.

3. Results and conclusions

In all three forest fire seasons the smallest percentage of high class (value 6) of low-elevation Haines Index was noticed. Such a small proportion of high class was desirable and expected. Surprise was a large proportion of moderate class (value 5), which stands out in comparison to the other classes (Figure 1). This was the case for a whole data set and separately for sets at 00 and 12 UTC.

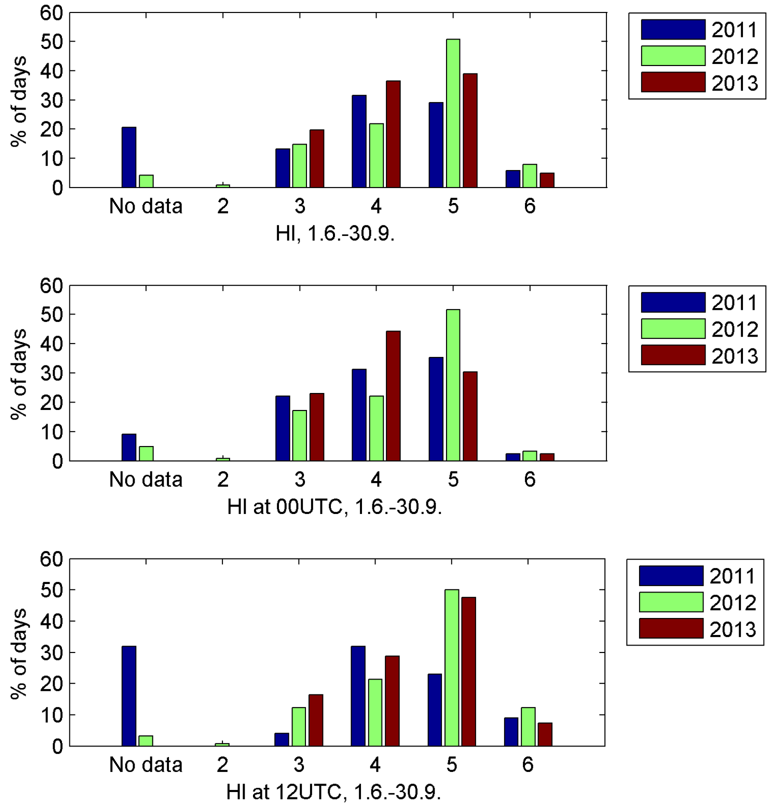

Figure 1. Distribution of Haines Index calculated from upper air soundings at Zadar station for three forest fire seasons. 12 UTC data set is shown in the lower plot, 00 UTC in the middle and a whole data set is in the upper plot. Missing data were also taken into account.

The resulting distribution of Haines Index did not match distributions found in the literature. The possible issue was strange distribution of the stability term A with too large proportion of value 3 (not shown). With a given distribution the performance of low-elevation variant Haines Index as a marker of severe fire weather conditions in the Zadar/Adriatic area may be reduced. But as already mentioned, the further plan is to test the middle-elevation variant in the calculation of Haines Index, in other words taking into account the effects of higher topography. Also a calibration of the original set up of Haines Index to the Mediterranean climate of the Adriatic can be carried out (particularly through tuning the thresholds of the stability term A) but this procedure requests for longer and more detailed data series of forest fires in the Adriatic region.

In any case there was an obvious relationship between Haines Index and forest fires in Adriatic region, particularly Zadar area. Haines Index at 12 UTC showed similar connection to the forest fires behaviour as Haines Index at 00 UTC but with a little bit better correlation, probably because daylight heating of land surface still had some small effect on instability in the upper levels.

In the majority of days of fire seasons the increase of the class of Haines Index was related to the increase of number of fires (Figure 2) and larger burned area (Figure 3).

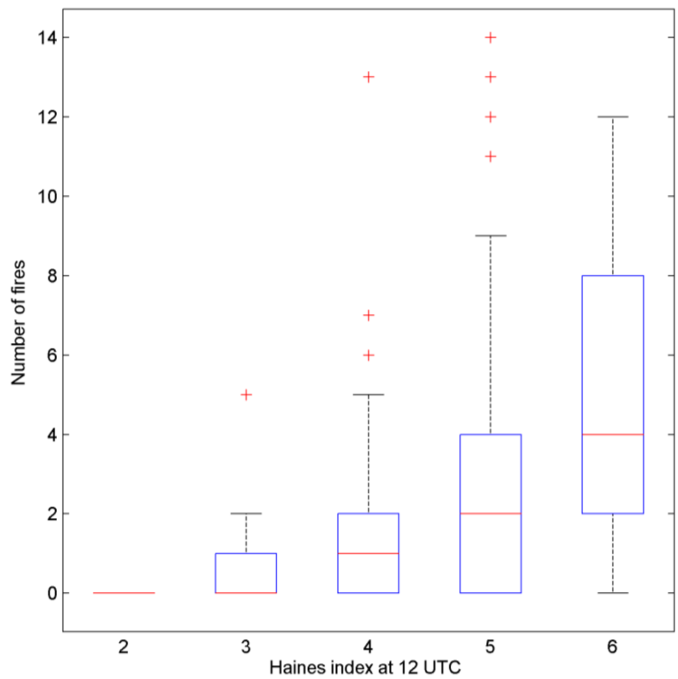

Figure 2. Box and whisker plot of the number of forest fires in one day against Haines Index class at 12 UTC same day. Red lines are medians, blue boxes represent interquartile range, black lines at the top of the whiskers are extremes and red pluses indicate outliers, i.e. cases not belonging to the set.

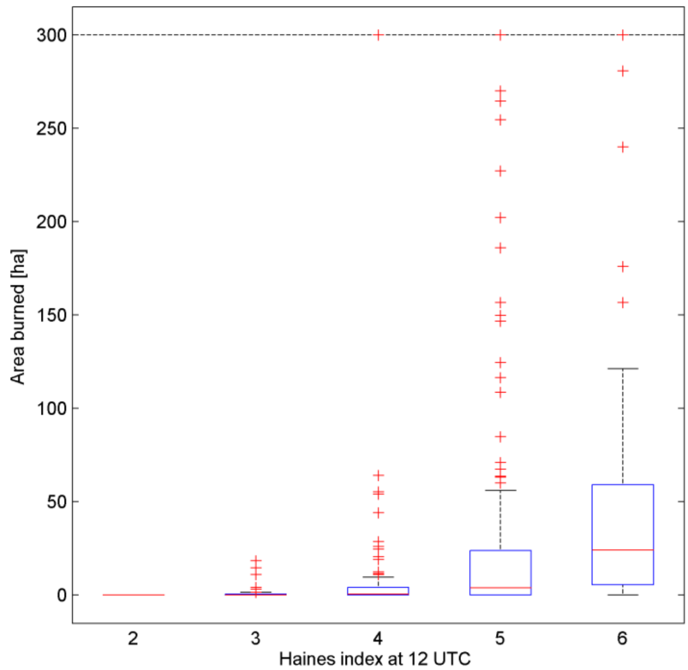

Figure 3. Same as Figure 2, but for an area burned in one day.

According to the results of box plot statistics the largest number of fires and the largest burned area were associated with the high class of Haines Index as seen in higher values of both median and upper quartile in comparison to moderate class and especially low classes. Despite the procedure of reducing size of long-lasting fires, there was still large number of outliers, especially for burned area. This could be explained by the fact the forest fires are not affected just by weather conditions but also by other factors, e.g. fuel availability, topographic characteristics, fire suppression efficiency and others.

The positive correlation of forest fires behaviour with the unstable dry air mass was even stronger when the three-day moving sums/averages were applied to the number of fires, burned area and associated Haines Index. Then the high class of Haines Index was pointed out the most as seen in Figures 4 and 5. Longer periods, in this case three consecutive days with unstable dry weather conditions had obviously strong impact on forest fire behaviour.

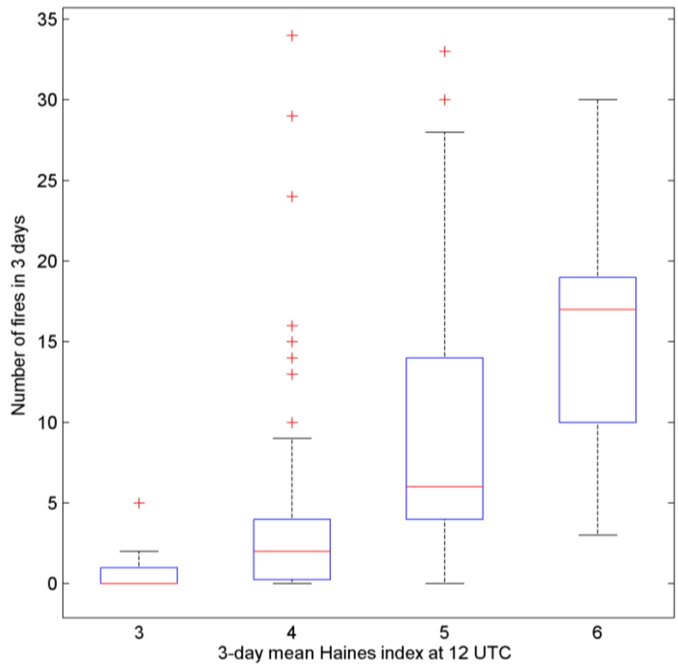

Figure 4. Box and whisker plot of a total number of forest fires in three days against three-day average of Haines Index classes at 12 UTC. Red lines are medians, blue boxes represent interquartile range, black lines at the top of the whiskers are extremes and red pluses indicate outliers, i.e. cases not belonging to the set.

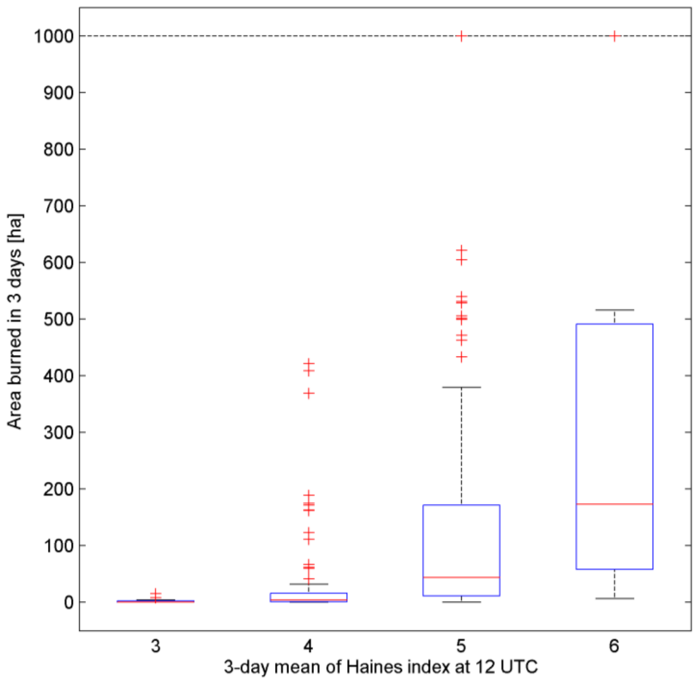

Figure 5. Same as Figure 4, but for a total area burned in three days.

Final conclusion is that the original set up of Haines Index can still be used in the Adriatic region of Croatia as an additional tool for issuing warnings on severe fire weather related to atmospheric instability. At least high class of Haines Index can be used what is currently the case in Croatia. However, as shown in this work, there is place for improvements and further research.

4. Acknowledgments

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Impacts of climate change on forest fire risk in Paraná State-Brazil

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Abstract

Forest fires are a global phenomenon due to the interaction between climate, fuels and human activities. Fires are also a critical component in the dynamics of planet earth and atmosphere. Recent advances in remote sensing products gathered via sensors on board satellites, have demonstrated the possibility of fire identification and monitoring on a global scale. The weather and climate are the major factors directly affecting fire and are being modified due to climate change caused mainly by man. There is an expectation of most researchers that changes in climate over the next 100 years will cause a major impact on forest ecosystems. The aim of this study was to determine, by decade, forest fire risk zoning for the State of Paraná, Brazil, based upon the scenarios predicted by the Intergovernmental Panel on Climate Change (IPCC) in 2007. Vegetation maps, fuel moisture, Monte Alegre Formula (FMA) for forest fire risk, slope, population density and road network, were used. These information, after being classified according to the risk of fire hazard, were weighted in a mathematical model. The determined values were then used to compose the Forest Fires Zoning Risk (ZRIF) per decade for the State of Paraná. Results showed that for the best scenario, which considers an increase of 1.8 ºC in the average temperature of the Earth by year 2100, there will be an increase in class extreme risk of forest fires, rising from 1.80% of the area of the State in 2020 to 8.49% in 2100. The same applies to the class of very high risk, which rises from 10.43% (2020) to 32.38% (2100). For the worst scenario, which considers an increase of 4.0 ºC in the average temperature of the Earth by 2100, the class of extreme risk rises from 2.18% (2020) to 22.72% (2100). The higher risk class rises from 13.93% (2020) to 55.95% (2100). It was concluded that, if the IPCC predictions were confirmed, there will be an increase in the number of occurrences and area affected by forest fires in the State of Paraná, which will require integrated actions to prevent and suppress forest fires to minimize environmental, social and economic damages.

Keywords*: forest fire risk, climate change, forest fire zoning risk, FMA fire risk*

1. Introduction

The effects of fire on the forests affect not only vegetation but also soil, fauna and atmosphere characteristics, and can be highly destructive when it is a forest fire. A fire occurs in the simultaneous presence of oxygen, fuel and heat source (Marques *et al*., 2011). According to the terminology of wildfires proposed by the Food and Agriculture Organization (FAO), "fire hazard" is defined as the probability of starting a fire due to the presence and activity of active causal agents. Also, "fire hazard" is used to express the degree of involvement of fixed and variables factors that determine the ease of ignition, rate of spread, difficulty of control and impact of fires, usually expressed as an index (FAO, 2007).

The assessment of the risk of forest fires is a critical part in fire prevention, since for pre-suppression planning and fire-fighting tools are needed to monitor when and where a fire can occur or when its effects will be more negative (Chuvieco *et al*., 2010).

Several factors may explain the ignition and spread of forest fires, such as: the characteristics of fuels, weather conditions, sources of ignition and topography. Fuel characteristics depend on the structure