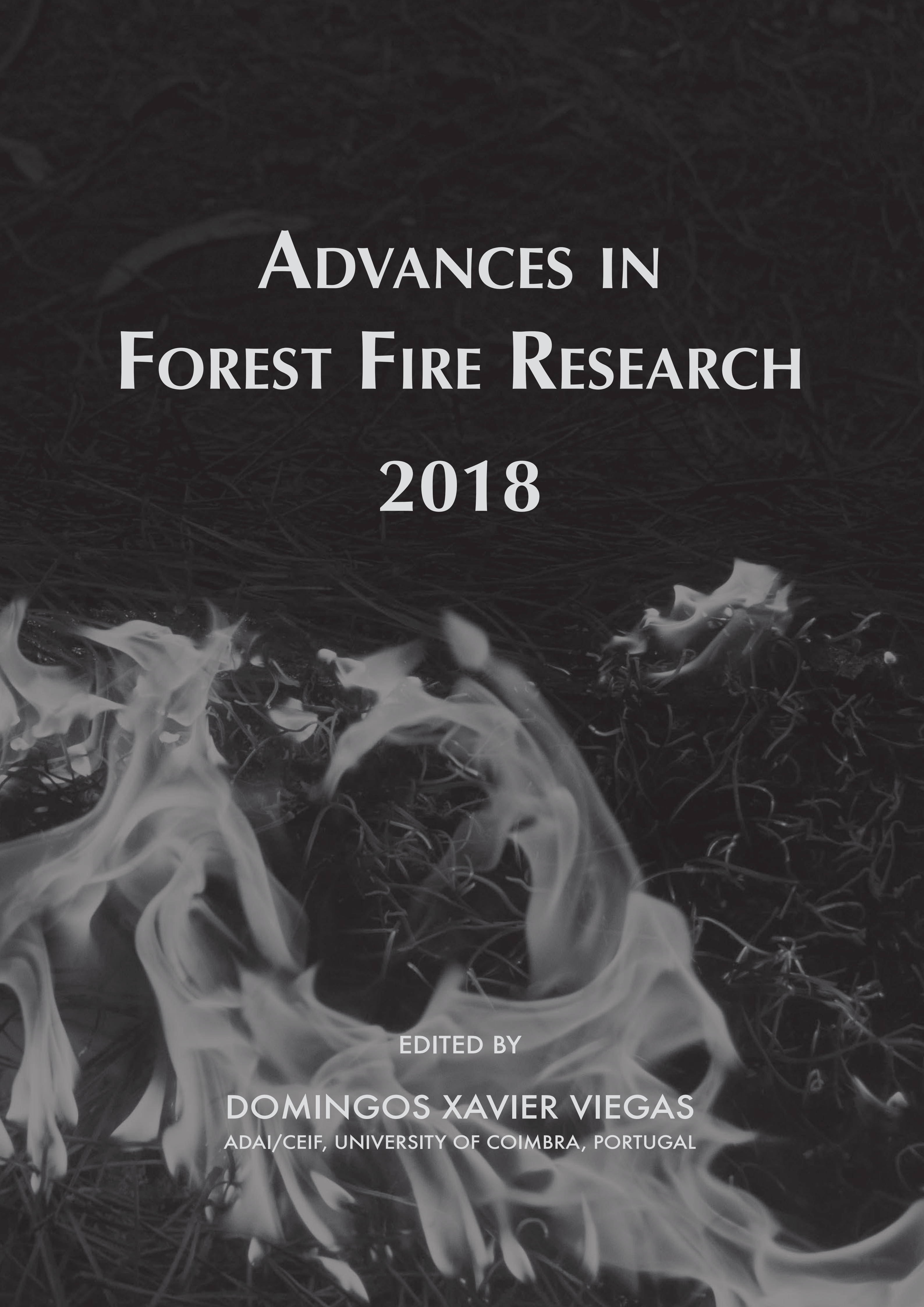

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Temporal variability of the Haines index and its relationship with forest fire in Portugal

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Abstract

The above-ground atmospheric conditions, such as atmospheric stability and moisture content, play a critical role in fire behaviour, especially for larger fire. The Haines Index and Continuous Haines Index are widely used as a measure of above ground conditions relevant to wild land fire, especially in Australia. This work presents the temporal variability of the Haines index and the continuous Haines index, and its relationship with the large forest fires in Portugal in the period from 2011 to 2017.

Keywords: Forest Fire Risk, Haines Index, Continuous Haines Index

1. Introduction

Forest fires are one of the most important natural hazards affecting Portugal, especially during summer time, with enormous economic and social impact. They are also indirectly responsible for fast changes on the land cover. Wildfires typically occur during periods of increased temperature and drought.

Among the fire risks that are dependent on meteorological parameters, the most usual and known one is the FWI (Canadian Fire Weather Index), used in several countries since the mid-1990s. However, the above-ground atmospheric conditions, such as atmospheric stability, also play a critical role in fire behaviour, especially for larger fires. In 1988 Haines (Haines, DA 1988) developed the Lower Atmosphere Stability Index, or Haines Index (HI). It is used to indicate the potential for wildfire growth, given ignition has occurred. It measures the stability and dryness of the air over the fire. The HI is widely used as a measure of above ground conditions relevant to wild land fire (Potter, BE et al, 2003, Potter, BE et al, 2008, Taitl, H. et al, 2014) and it is derived from the stability (temperature difference between different levels of the atmosphere) and moisture content (dew point depression) of the lower atmosphere. The Continuous Haines Index (CHI) was developed in Australia (Mills, GA et al, 2010), since climatology conditions in Australia were considerably different compare with the original used to develop the Haines Index. For the climatology conditions in Portugal, the CHI seems also more appropriate than the HI.

Management decisions for wild fires incorporate a vast array of factors that are weighted differently. These factors can be infrastructure at risk, resources available, fuel conditions, weather conditions, firefighter safety, public safety from fire and smoke. The relative weights of the factors are highly dependent on the local specific situation, such as population density or the type and stress of the vegetation, and the uncertainty or reliability of any data used in the decisions is an important piece of information. This knowledge includes the description of the climatological characteristics of the indices HI and CHI and their sub-indices, stability term (term A) and moisture term (term B). In this work the HI and CHI indices are analyzed in their temporal variability, annual and monthly, and in their relationship with periods of large forest fires. The results are presented for the period from 2011 to 2017. The main objective of this work is to understand the behavior of HI and CHI in Portugal.

2. Method

2.1. Haines and Continuous Haines Index

The stability and moisture content of different atmospheric levels are generally used terms to assess the risk in the propagation and evolution of a forest fire, assuming ignition occurs. The HI combines these two terms to determine the environmental potential for the growth of forest fires. Knowledge of typical HI values, together with the weather conditions that generate them, can be extremely useful in prevention and planning specific fire-fighting strategies. The calculation of the HI is performed according to Table 1, where the risk values associated to the stability term (term A) and values of risk associated with the term of humidity (term B) are found. The sum of the two terms is the value of the HI.

The higher the value of term A, the more unstable the atmosphere is, and the higher the probability of fires dominated by convective feathers. Similarly, drier atmospheric conditions, that are higher values of term B, favor the propagation of forest fires. Thus, HI values of 5 or 6 indicate critical conditions for the formation of convective feathers and high propagation speeds.

Table 1 - Variables and scales for calculating the Haines index according to the altitude of the place (Haines, 1988; Choi et al., 2006, Potter et al., 2008)

Surface Elevations	Pressure Level	Stability (*TP1 – TP2*)	*A*	Humidity (*TP3 – TdP3*)	*B*	*HI=A+B*
< 305 m (low)	P1=950 hPa (925 hPa) P2=850 hPa P3=850 hPa	< 4ºC (2,7ºC)	1	< 6ºC	1	Potential for large fires 2-3: very low 4: low 5: mid 6: high
		≥ 4ºC (2,7ºC) < 8ºC (6,7ºC)	2	≥ 6ºC <10ºC	2	
		≥ 8ºC (6,7ºC)	3	≥ 10ºC	3	
305 – 914 m (mid)	P1=850 hPa P2=700 hPa P3=850 hPa	<6ºC	1	< 6ºC	1	
		≥ 6ºC < 11 ºC	2	≥ 6 ºC <13ºC	2	
		≥ 11ºC	3	≥ 13ºC	3	
> 914 m (high)	P1=700 hPa P2=500 hPa P3=700 hPa	< 18ºC	1	< 15ºC	1	
		≥ 18 ºC < 22ºC	2	≥ 15ºC < 21ºC	2	
		≥ 22ºC	3	≥ 21ºC	3	

Both HI and CHI combine a term of humidity and a term of stability to predict the potential for fire propagation given ignition occurs. The difference between the two is that instead of assigning a score to each term resulting in a value between 2 and 6, the CHI ranges any value between 0 and approximately 14. The CHI index eliminates the abrupt transitions between the categories and provides greater discrimination at high values. It also allows a more realistic assessment of the contributions of atmospheric instability and dew point depression to the overall score. For this reason, the CHI index is now included, together with other indices, in operational activities in Portugal.

The calculation of the CHI index is performed using the following equations:

$$CA = 0.5\,(T850 - T700) - 2. \qquad \text{(continuous stability term, CA)}$$

$$CB = 0.3333\,(T850 - DP850) - 1 \qquad \text{(continuous moisture term, CB)}$$

$$CHI = CA + CB$$

Subject to the following conditions:

If (T850 - DP850)> 30 °C, then (T850 - DP850) = 30 °C

If CB> 5., then CB = 5. + (CB - 5.) / 2.

Here, T850 is the temperature for the 850 hPa level, T700 is the temperature for the 700 hPa level and DP850 is the dew point temperature for the 850 hPa.

As mentioned, one of the features of the CHI was to obtain greater discrimination at higher values of risk. Terms CA and CB have an upper limit of approximately 6.5 and 7, respectively. Thus, the upper limit of the proposed CHI is approximately 14. There is no specified lower limit, but that is not the range of interest. In the datasets developed in this study, the values are limited so not to be less than zero.

2.2. Data

The meteorological data were obtained from the analysis of the European Centre for Medium-Range Weather Forecasts (ECMWF) atmospherics' model, with grid spacing of approximately 16 km (0.125º latitude and longitude) from 2011 to 2017, at 00, 06, 12 and 18 UTC.

The computation of HI and CHI require temperature values at the 950, 850, 700 and 500 hPa pressure levels, and dew point temperatures at the 850 and 700 hPa levels. In the absence of information for the 950 hPa level, the required data, namely the temperature, was obtained by interpolation between two levels containing the 950 hPa. This level is only required for land altitudes lower than 305m (see Table 1).

The HI and CHI statistical values, such as monthly averages, percentiles, number of days with value above a certain threshold, were calculated for each pixel in a rectangle containing Portugal, between latitudes 41.875ºN and 36.25ºN and longitudes -6.0W and -9.375W. The calculations were made on a monthly basis, considering the values for each hour (00, 06, 12 and 18 UTC) and for each day. One of the most important information is the number of days with CHI value above threshold 10, considered to be a very high-risk value. If the CHI exceeds 10 at any of the times 00, 06, 12 or 18 UTC, in any pixel point, of a certain day, then that day is accounted as a day with CHI value above 10. Indeed, Gwangyong Choi showed that daily high HI and its monthly frequency have statistically significant correlations with the frequency of the wildland fire occurrences during the fire season (December-April) in South Korea, (Gwangyong Choi et al, 2006).

The forest fire data was obtained from the Instituto da Conservação da Natureza e das Florestas (ICNF). Monthly data were obtained for the period 2011 to 2017.

3. Climatological Characterization of the Haines Index and Continuous Haines Index in Portugal

3.1. Climatology of the Haines Index (HI) in Portugal

The average monthly values of HI for mainland Portugal are shown in Figure 1. Here, the HI daily value is the average of all pixels. for 00, 06, 12 and 18 UTC. The average monthly values of HI show lower values in January, February, November and December, ranging approximately from 3.6 to 3.7. The higher of HI are in July and August, ranging between 4.4 (at 06UTC) and 5.0 (at 18 UTC). HI values range from 2 to 6, hence mean values of 4.5 or 5.0 in one month indicate that high daily values, namely above 5, occur with high frequency in almost all the country's pixels.

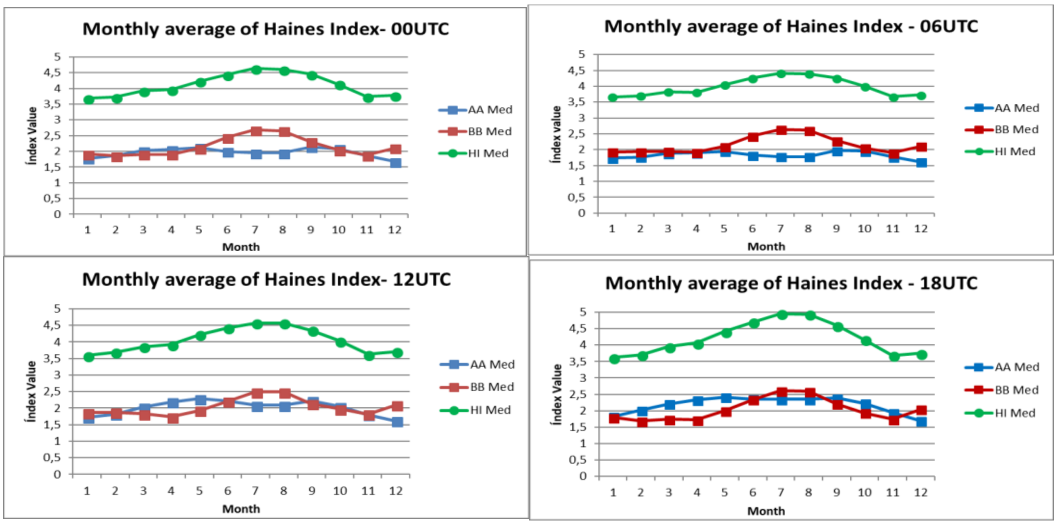

Figure 1 - Average monthly value of the Haines Index (HI) and the sub index A (term associated with stability) and B (term associated with moisture content), at 00, 06,12 and 18 UTC for Continental Portugal in the period 2011-2017

Between 00 UTC and 18UTC, Figure 1, the average monthly values show a slight difference with the highest average values (July and August), around 5.0, attained at 18UTC, while the lowest values, approximately 4.4, occur at 06UTC and at 12 UTC. The monthly average values of the sub indices, ranging between 1 and 3, do not vary much. The sub index values associated with atmospheric stability (term A) do not change much on a monthly basis, with slightly higher values in May and September, which are months of frequent instability. The sub index values associated with the moisture content (term B) do not vary much either. This sub-index has its lower values in April and November, which are months that are usually associated with higher rainfall and humidity. On the other hand, its higher values occur in July and August, which are months climatologically characterized by low precipitation and dry conditions.

In Figure 2 are presented the values of HI for August at 12 UTC in mainland Portugal. August is one of the months with highest monthly values of the HI. It can be observed that great part of the country presents an average monthly value of 4, with some parts of Alentejo region reaching 5. For August at 12 UTC, the 95th percentile is 6 (HI maximum value) throughout the country, except for the coastal zones (see Figure 2). This spatial distribution of the 95th percentile was observed for other hours.

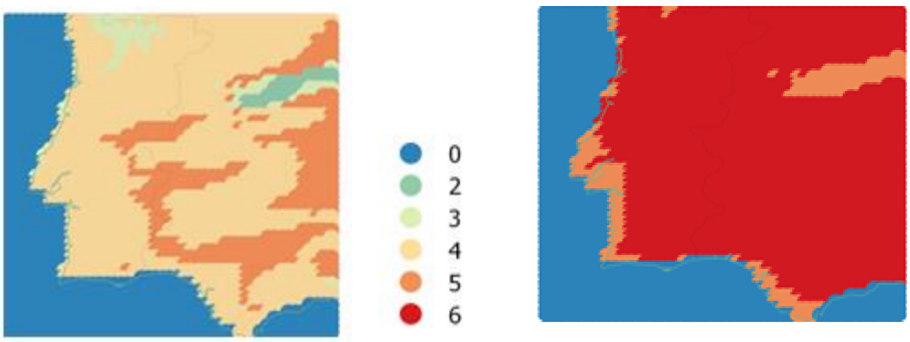

Figure 2 - Maps of the spatial distribution (per pixel) of the monthly average HI value (left) and the 95th HI percentile (right) for August at 12 UTC.

3.2. Climatology of the Continuous Haines Index (CHI) in Portugal

The average monthly values of CHI are presented in Figure 3 for 00, 06, 12 and 18 UTC. We observe that the lower monthly average values occur in January, February, March, April, November and December, corresponding to winter months, early spring and late fall. The highest monthly average values are observed in July and August. It can also be seen from Figure 3 that the average monthly values at 18UTC are generally slightly higher than at other hours, especially in July.

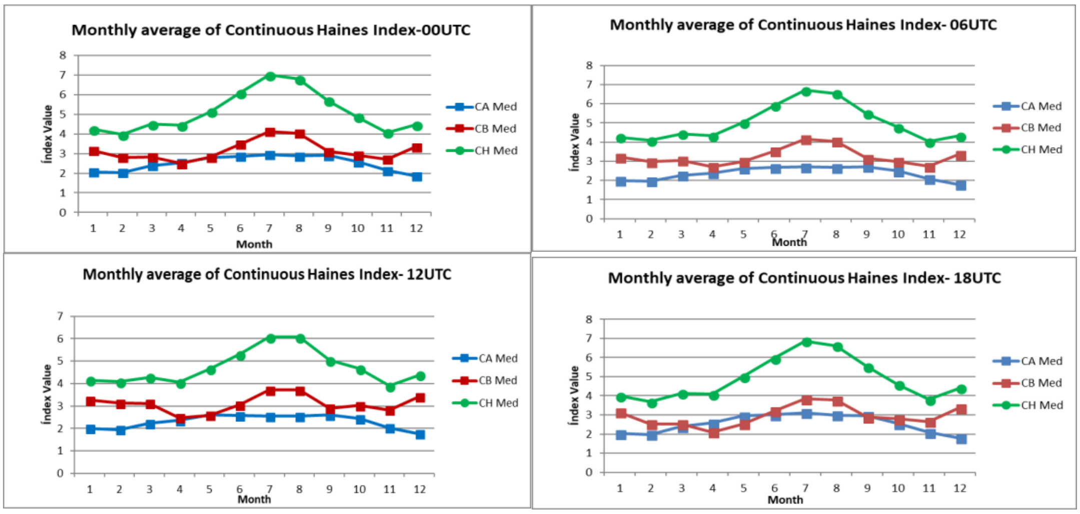

Figure 3 - Average monthly value of the Continuous Haines Index (CHI) and the sub index CA (term associated with stability) and CB (term associated with moisture content), at 00, 06, 12 and 18 UTC for mainland Portugal.

As expected, the term associated with moisture content (CB) exhibits higher monthly average values in the summer, followed by the winter. In spring and autumn, slightly lower monthly average values are observed. Regarding the monthly average values of the term associated with stability (CA), they present a small monthly variation but with slightly higher values from May to September. For what concerns the monthly values of the 95th percentile of the CHI, it is observed that these are high throughout the country. Furthermore, they do not vary much from January to December, with slightly higher values from June to August and with lower values in November and December. This variation is most pronounced at 18UTC. The term CA associated with the atmospheric stability in the 850-700 hPa layer presents slightly higher 95th percentile values between May and October, compared to the remaining months of the year.

For a better understanding of the behavior of CHI, it is necessary to analyze the extreme cases, looking at the maximum values of the index. Figure 4 illustrates the maximum value of CHI for mainland Portugal in the period from 2011 to 2017.

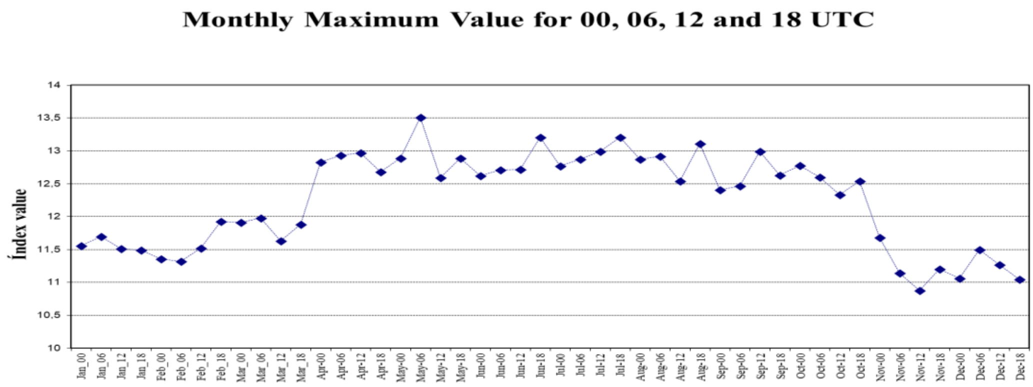

Figure 4 - Maximum monthly value of CHI at 00, 06, 12 and 18 UTC, from 2011 to 2017, for Portugal.

From Figure 4, CHI monthly maximum values are always greater than 10, for all months, for all the considered hours (00, 06, 12 and 18 UTC), and in the study period from 2011 to 2017. In months from January to March, the monthly maximum values for the considered hours were between 11.3 and 12. In months from April to October the maximum values of range from 12.3 to 13.5, above 12, which is an extremely high value. The maximum values for the study period are higher than 13 for May at 06UTC and for June, July and August at 18 UTC.

***Figure 5** - Map of the monthly maximum CHI value at 18 UTC, for months from April to October, in the period from 2011 to 2017.*

The spatial CHI distribution of the monthly maximum values at 00, 06, 12 and 18 UTC was also analyzed. In particular, Figure 5 shows the monthly maximum values per pixel at 18UTC from April to October, in the study period ranging from 2011 to 2017. From April to October, at 18UTC, some pixels with CHI peak values, between 12 and 14, are observed. In April and May the highest peak values of CHI, above 12, are observed in the southern coast region. In May, peak values above 12 are also observed in the coastal region, north of Cabo da Roca. From June to August, maximum values of CHI higher than 12 are observed in general in the interior regions. This spatial distribution of CHI peak values is consistent with the fact that in the summer the conditions of great dryness are frequent, as well as instability conditions. This dryness and instability conditions are particularly noticeable in the southern and interior regions in the period from middle afternoon to night's beginning.

The number of days per month with CHI values above 10 was also analyzed and it is shown in Figure 6. From the results, it can be seen that:

- The months of May to October usually have a greater number of days with a CHI index greater or equal to 10;
- July and August show the highest values (25 in July 2015 and 25 in August 2016);
- 2017 had the highest number of days with CHI greater or equal to 10 of March, April and October months from 2011 to 2017;
- 2015 had the highest number of days with CHI greater or equal to 10 of June and July months from 2011 to 2017;

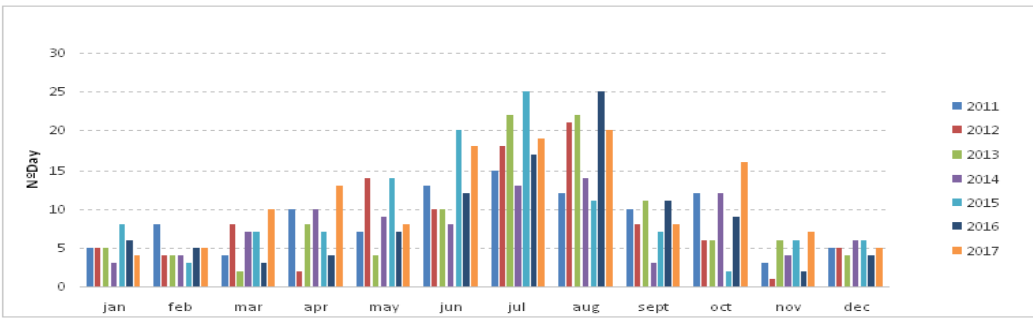

***Figure 6** - Number of days with CHI value equal to or greater than 10, per month and per year, from 2011 to 2017.*

It is interesting to note that in March 2012, when large forest fires and several fire events occurred, the number of days with CHI larger or equal to 10 was almost has high as in 2017. Also, the large fires, with convective feathers, that occurred in 2017 happened in June and October, when the number of days with CHI greater or equal to 10 was also very high.

The spatial distribution of the number of days with CHI greater or equal to 10 can be seen in Figures 7, 8 and 9 for June, August and October months, respectively. From these figures we can observe the regions with the highest frequencies of high CHI values, that is, with the higher number of days with CHI larger or equal to 10.

From Figure 7, regarding June, we can see that in 2015 and 2017 the frequency of days with CHI higher or equal to 10 was very high, compared with the remaining years. Namely, in the central and southern interior regions and the north and central coast. In 2017 this was also observed in the central coast regions, where the June fires occurred. 2016 and 2014 were the years with the lower values, between 1 and 3 days, in almost all the country.

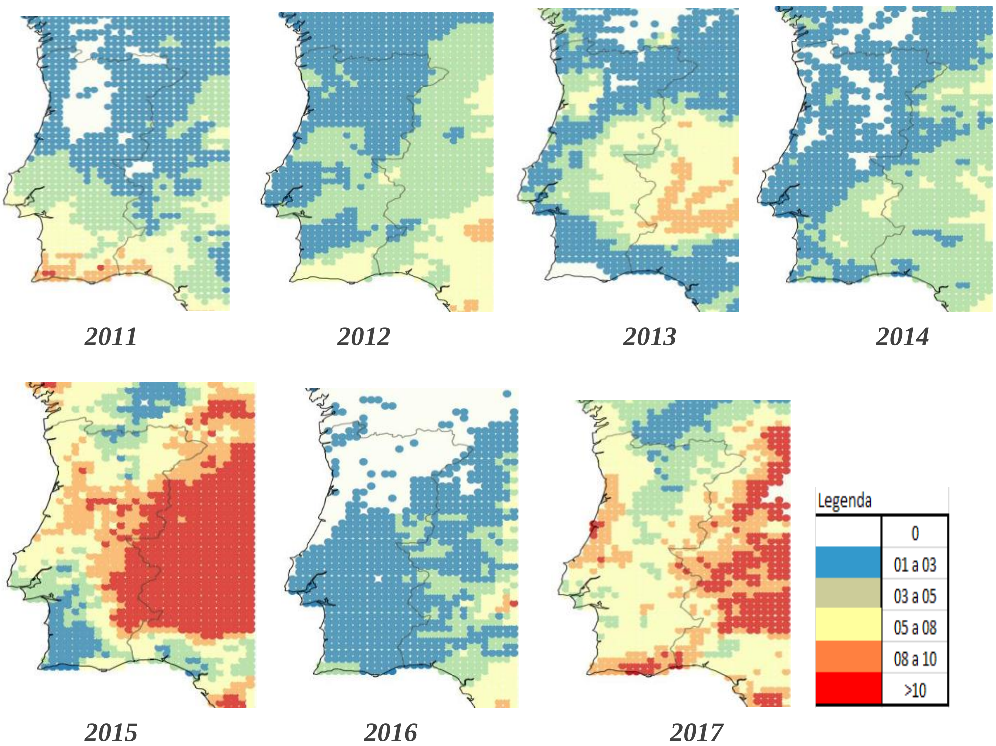

Figure 7 - Maps of the spatial distribution of the number of days with a CHI value greater or equal to 10 in June, in the period from 2011 to 2017

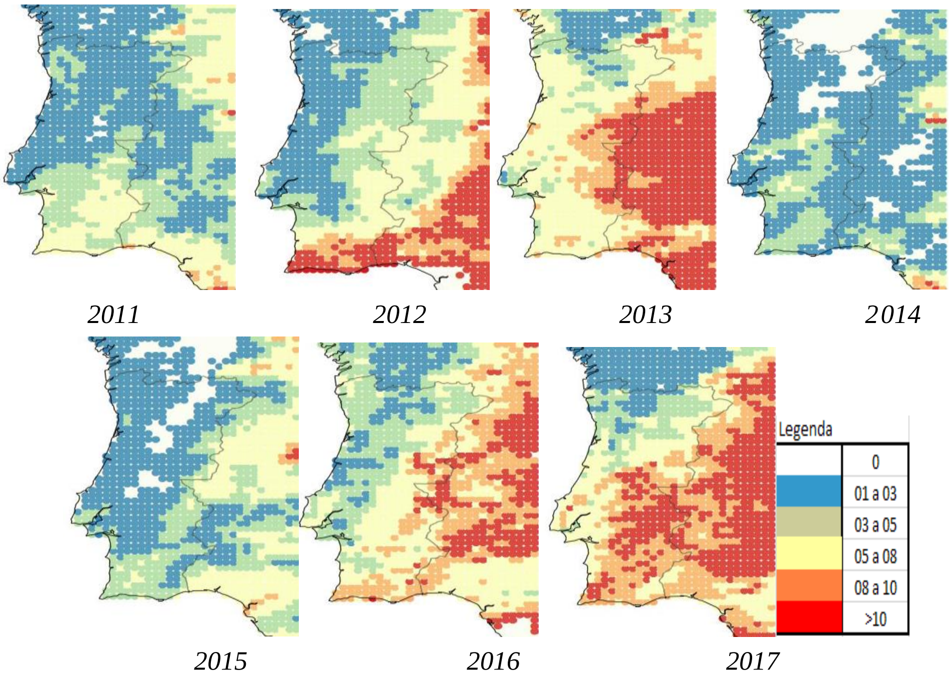

Figure 8 - Maps of the spatial distribution of the number of days with a CHI value greater or equal to 10 in August, in the period from 2011 to 2017

From Figure 8, regarding August, which is a month generally associated with forest fires, we find that the regions with the higher number of days with CHI greater or equal to 10 are the interior and south. The years with the highest values were 2012, especially in the southern region, 2013 and 2016, in the interior, central and southern regions, and 2017, in the entire central and southern region. We also observe from Figure 8 that in 2013 the number of days with CHI greater or equal to 10 was abnormally high throughout the country, including the western coastal regions. This situation was again observed in 2017, where values were abnormally high throughout the central and southern regions. It should be noted that even in the coastal region north of Cabo da Roca, the values were the highest in the period from 2011 and 2017.

From Figure 9, concerning October, very low values are observed in general, with very few days with values of the CHI larger or equal to 10. Exceptions were the years of 2014, especially in the regions of the south, 2011 throughout the country, and especially 2017, also throughout the country. In 2017 some regions, such as near Aveiro and in some regions of the center, had a high frequency, more than 10 days, with CHI greater or equal to 10. This represents an extremely high value for October month, and corresponds to the regions and time of the largest forest fires.

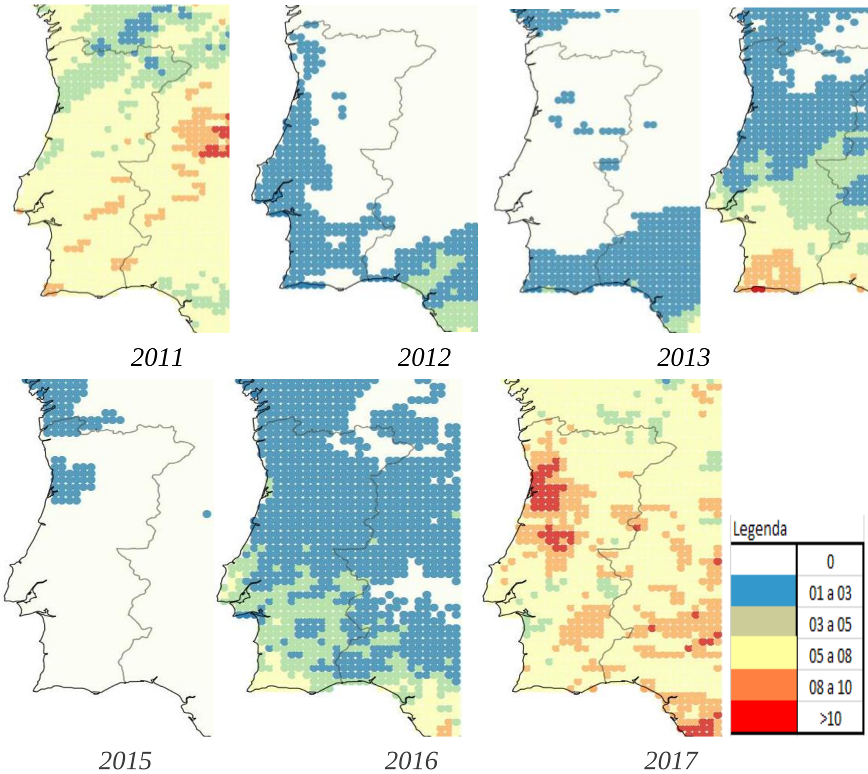

Figure 9 - Maps of the spatial distribution of the number of days with a CHI value greater or equal to 10 in October, in the period from 2011 to 2017

3.3. Continuous Haines Index (CHI) and Forest Fire Data

The value of the Pearson correlation between the number of days with CHI larger or equal to 10 and the monthly burned area data, in the period from 2011 to 2017, is 0.46. Also, the Pearson correlation between the number of days with CHI larger or equal to 10 and the number of occurrences of forest fires is 0.63, in the same period. The years with the highest burned areas of the study period were 2017, followed by 2016 and 2013. The correlation for these three years were 0.56, 0.81 and 0.77, respectively for 2017, 2016 and 2013, for the burnt area, and 0.81, 0.84 and 0.93, respectively for 2017, 2016 and 2013, for the number of fire events. The behavior of the burnt area and number of fire events for these three years are depicted in Figures 10, 11 and 12, for years 2013, 2016 and 2017, respectively.

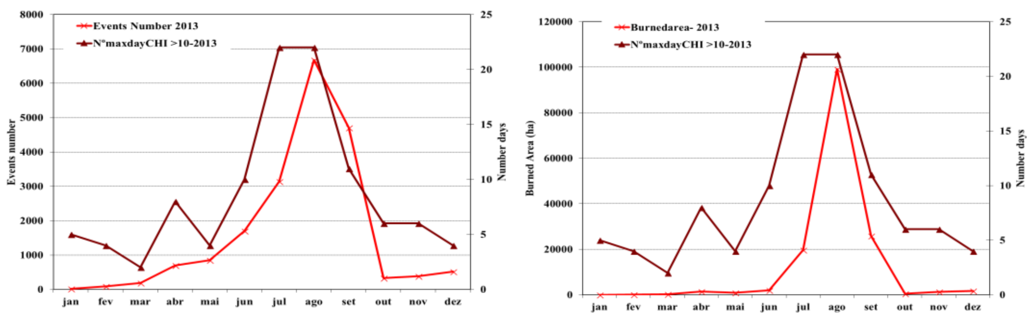

Figure 10 - Monthly values of the number of events (left) and burnt area in ha (right) of the forest fires and number of days with values of CHI≥10, in 2013.

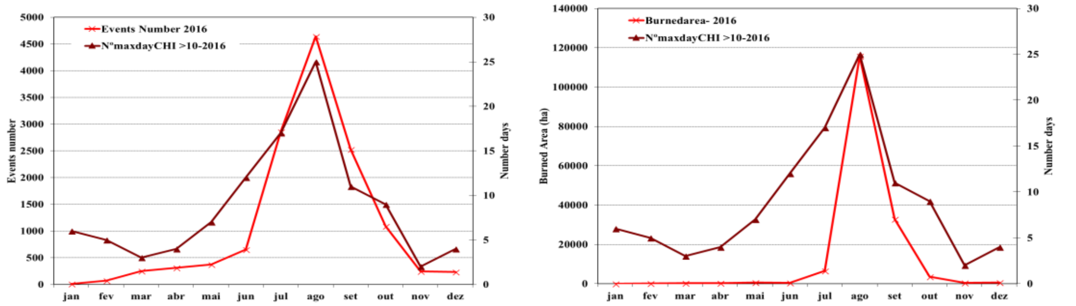

Figure 11 - Monthly values of the number of events (left) and burnt area in ha (right) of the forest fires and number of days with values of CHI≥10, in 2016.

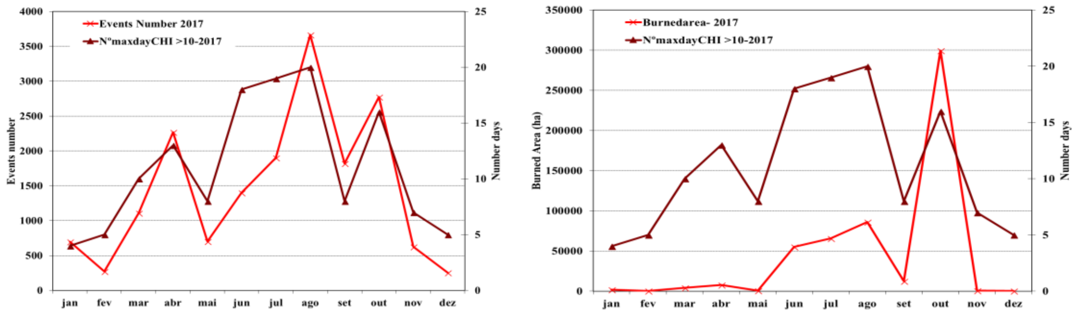

Figure 12 Monthly values of the number of events (left) and burnt area in ha (right) of the forest fires and number of days with values of CHI≥10, in 2017.

4. Conclusions

In recent years there has been increasing awareness of the importance of the vertical structure of the low atmosphere in the formation of catastrophic forest fires. All forest fire risk indices provide information that may help in prevention and firefighting strategies. The importance of the Continuous Haines Index (CHI) is that it provides information on the stability conditions and the moisture content, generally above the boundary layer of the atmosphere, between 850 and 700 hPa, completing the information given by calculated risk indices with surface data.

The study period, from 2011 to 2017, may be small given the variability of favorable weather conditions for forest fires. It should be noted that the year 2017, having been a year with very burdensome conditions for forest fires and abnormally high areas burned in forest fires, has a great influence on statistical values.

In relation to the climatology of CHI in Portugal we can conclude the following.

- The highest values of CHI occur from April to October, with maximum values occurring at 18 UTC from June to August;
- The regions of the south coast and the interior are where the highest values of CHI are reached. Namely, CHI peak values, ranging from 12 to 14, are observed in the July and August in the southern regions and at all hours;
- The maximum values of CHI are observed in general in the interior regions at 18 UTC, especially in July and August;
- The months from May to October usually have a greater number of days with a CHI index greater or equal to 10, with July and August having the highest frequency.

The frequency of high values of this index, given by the number of days with high values, relates well to the areas burned and to the number forest fire events. This is particularly observed for years with larger burnt areas. We can hence conclude that the number of days with CHI larger or equal to 10 is a relevant indicator for characterizing conditions favorable to forest fires.

5. References

Gwangyong Choi, Junsu Kim, and Myoung-Soo Won, (2006) - Spatial Patterns and Temporal Variability of the Haines Index related to the Wildland Fire Growth Potential over the Korean Peninsula, Journal of the Korean Geographical Society, Vol. 41, No. 2, 2006(168~187)

Haines, D.A. 1988. A lower atmospheric severity index for wildland fire. National Weather Digest. Vol 13. No. 2:23-27.

Littell, J. S., McKenzie, D. , Peterson, D. L. and Westerling, A. L. (2009), Climate and wildfire area burned in western U.S. ecoprovinces, 1916–2003. Ecological Applications, 19: 1003-1021. doi:10.1890/07-1183.1

Mills, Graham A. and Lachlan McCaw, 2010: Atmospheric Stability Environments and Fire Weather in Australia – extending the Haines Index CAWCR Technical report No. 20 March 2010

Potter BE. 1996. Atmospheric properties associated with large wildfires. Int. J. Wildland Fires 6: 71–76.

Potter BE, Goodrick S. 2003. Performance of the Haines Index during August 2000 for Montana. In Proceedings of the 4th Symposium on Fire and Forest Meteorology, 13–15 November 2001, Reno, NV . American Meteorological Society: Boston, MA; 233–236.

Potter BE, Winkler JA, Dwight FW, Ryan PS, Xindi B. 2008.Computing the low-elevation variant of the Haines Index for fire weather forecasts. Weather Forecast. 23: 159–167.

Pyne, S. J., Andrews, P. L., and Laven, R. D.: Introduction to wildland fire, 2 edition, Wiley, New York, 769 pp., 1996

Tatli, H. and Murat T¨urkes, (2014):"Climatological evaluation of Haines forest fire weather índex over the Mediterranean Basin" Meteorol. Appl. 21: 545–552 (2014) Published online 22 February 2013 in Wiley Online Library (wileyonlinelibrary.com) DOI: 10.1002/met.1367

Vázquez A, Moreno JM (1993) Sensitivity of fire occurrence to meteorological variables in Mediterranean and Atlantic areas of Spain. Landscape and Urban Planning 24,129–142.

Williams, R. J., Gill, A. M., and Moore, P. H. R.: Seasonal Changes in Fire Behaviour in a Tropical Savanna in Northern Australia, Int. J. Wildland Fire, 8, 227–239, 2001

Williams, A., Karoly, D., and Tapper, N.: The sensitivity of Australian fire danger to climate change, Climatic Change, 49, 171–191, 2001.

Viegas, D., Bovio, G., Ferreira, A., Nosenzo, A., and Sol, B.: Comparative study of various methods of fire danger evaluation in southern Europe, Int. J. Wildland Fire, 9, 235–246, 1999.