ADVANCES IN FOREST FIRE RESEARCH 2022

Edited by
DOMINGOS XAVIER VIEGAS
LUÍS MÁRIO RIBEIRO

Joint Drought-Temperature conditions as factors contributing to the occurrence of forest fires in Portugal: a NUT III clustering perspective in a monthly/seasonal time scale

Nuno Moreira*[1]; Ilda Novo[1]; Pedro Silva[1], Edna Cardoso[1,2]; Álvaro Silva[1]; João Ferreira[1]; Ricardo Ramos[1]

[1]*IPMA. Rua C do Aeroporto 1749-077 Lisboa, Portugal*
{nuno.moreira, ilda.novo, pedro.silva, alvaro.silva, joao.ferreira, ricardo.ramos}@ipma.pt
[2]*University of Coimbra, FCTUC, Department of Mechanical Engineering. Pólo II*
Rua Luís Reis Santos, 3030-788 Coimbra, Portugal, *{uc2004118633@student.uc.pt}*

**Corresponding author*

Keywords

Drought, Temperature, Forest Fires, Clustering, NUT III

Abstract

The objective of the present work is to find a joint relation of drought and temperature regimes as factors contributing to the occurrence and severity of forest fires in the period 1981-2018 in mainland Portugal. To meet this goal PDSI drought data in NUT III regions from automatic weather stations were matched with temperature regimes obtained from a 3 km downscaling using WRF model and ERA5 reanalysis as forcing data. Clustering analysis was used to aggregate seasons from June to October, according to the weather-climate conditions provided together by drought and temperature regimes. The proposed scheme may be used to compare a seasonal forecast with this database and find a better match in order to support seasonal forestry and forest fire management policies. An additional analysis, also with SPI3 and SPI6 drought indices, was carried out to evaluate the influence of pre-season drought/wet conditions on the forest fire season.

1. Introduction

To better understand Extreme Fire Event conditions at a regional level in Portugal in the scope of the FIRESTORM project a preliminary independent analysis on drought conditions and on forest fires was performed in NUT III administrative organization in the period 1980-2019 (Cardoso *et al*, 2022). This analysis supports a more comprehensive study on the regional level on the relation between weather-climate conditions (drought, temperature, wind) and forest fires (occurrences, burned areas). In the current work the weather-climate conditions are focused on drought and temperature.

2. Data

To classify drought, two indexes were considered – PDSI (Palmer Drought Severity Index) and SPI (Standardized Precipitation Index), the last one for 3 and 6 months configurations (see e.g. Pires *et al.*, 2010, Silva *et al.*, 2014 and Pires *et al.*, 2019). The computation was based on weather station observations in mainland Portugal, with aggregation in 23 NUT III regions on a monthly basis. To classify the temperature regime a 3 km downscaling using the Weather Research and Forecasting (WRF) model and the fifth generation of European ReAnalysis (ERA5) as forcing data were used. Namely, monthly means of maximum temperature were considered over mainland Portugal grid points, that is, a mask was used to exclude grid points over the ocean and Spain. Drought and temperature data were analysed in the period 1981-2018. For the analysis of forest fires, data on occurrences and burned areas, both on a daily and monthly basis, were compiled from the Portuguese records of fire occurrence for the same period (ICNF, 2020).

3. Joint relation scheme of drought and temperature – a seasonal approach

A first step to see how the years could be clustered regarding drought and temperature was to set the most critical months for forest fires in Portugal. These months were set to be the ones between June and October, considering the number of occurrences per month in the dataset (see Figure 1). In this work, these 5 months together are considered a season. For this purpose, each month between June and October in mainland Portugal was reclassified regarding drought index into 4 classes: i) very dry, ii) dry, iii) normal, iv) wet or very wet - depending on the number of NUT III regions and their drought PDSI classification (extreme drought, severe drought, moderate drought, mild drought, near normal, slightly wet, moderately wet, very wet, extremely wet). The reclassification is described in Table 1. A season classification (also with 4 classes) is consequently computed from monthly drought reclassifications, using the percentiles 40, 60 and 90, as described in Table 2.

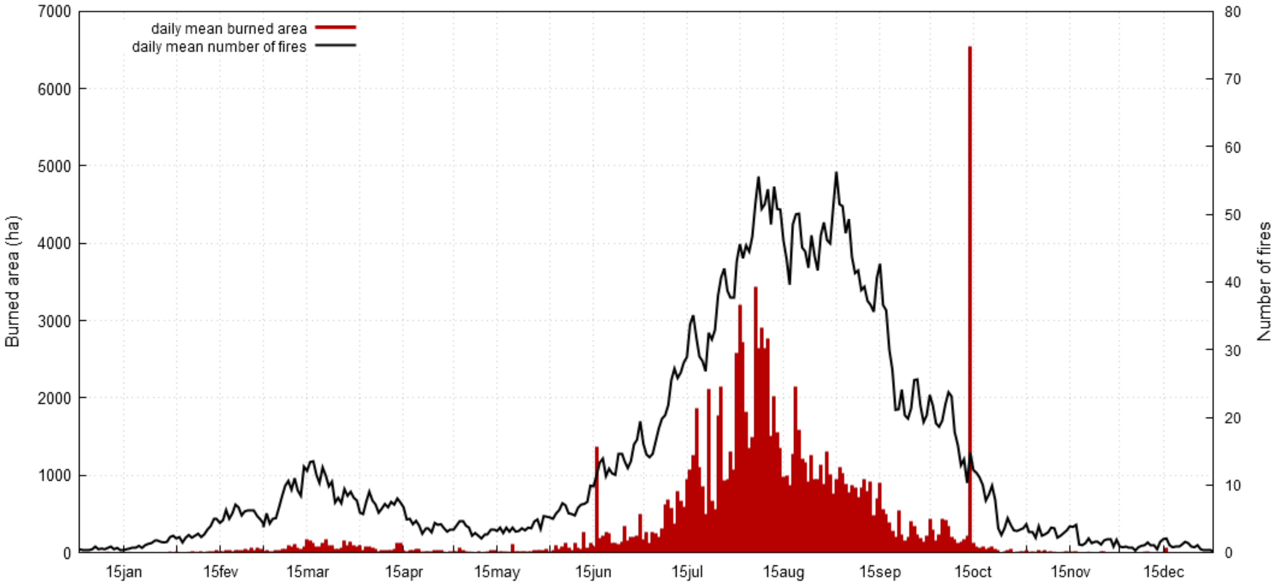

Figure 1- Daily mean values of burned area and number of fires (>1 ha), between 1980 and 2018, retrieved from the Portuguese records of fire occurrence (ICNF, 2020).

Table 1 – Reclassification of drought for a particular month between June and October in mainland Portugal according to the NUT III PDSI drought classification.

Monthly reclassification		Criteria	
1	Very Wet	At least 12 NUT III very or extremely wet PDSI (> 50 %)	At least 18 NUT III in any PDSI wet class (> 75 %)
	Wet	At least 12 NUT III moderately or slightly wet PDSI (> 50 %)	At least 18 NUT III in any PDSI wet class (> 75 %)
2	Normal	If the criteria are not met for very dry, dry, wet or very wet	
3	Dry	At least 12 NUT III in moderate or mild drought PDSI (> 50 %)	At least 18 NUT III in any PDSI drought class (> 75 %)
4	Very dry	At least 12 NUT III in extreme or severe drought PDSI (> 50 %)	At least 18 NUT III in any PDSI drought class (> 75 %)

Table 2 – Season (June to October) classification for drought in mainland Portugal based on monthly reclassifications as described in Table 1.

Season classification (June to October)	Sum of monthly drought reclassification (1 to 4) between June and October from Table 1	Corresponding percentile
Wet	< 10	< 40
Normal	≥ 10 and < 11	≥ 40 and < 60
Dry	≥ 11 and < 16	≥ 60 and < 90
Very Dry	≥ 16	≥ 90

On the other hand, each month between June and October in mainland Portugal was also classified regarding temperature in 4 classes – cold, normal, hot and very hot – depending on the maximum temperature monthly mean percentile over the whole territory in that period of the year. This classification is described in Table 3. Like for drought, a season temperature classification in 4 classes is consequently computed from monthly temperature classifications using the percentiles 40, 60 and 90, as described in Table 4.

Table 3 – Classification of Temperature of a particular month between June and October in mainland Portugal according to maximum temperature monthly mean percentile over the whole territory (also in the period from June to October).

		Maximum temperature monthly mean percentile in period June to October
1	Cold	< 40
2	Normal	≥ 40 and < 60
3	Hot	≥ 60 and < 90
4	Very Hot	≥ 90

Table 4 – Season (June to October) classification for temperature in mainland Portugal based on monthly classifications as described in Table 3.

Season classification (June to October)	Sum of monthly temperature classification (1 to 4) between June and October from Table 3	Corresponding percentile
Cold	< 9	< 40
Normal	≥ 9 and < 11	≥ 40 and < 60
Hot	≥ 11 and < 14	≥ 60 and < 90
Very Hot	≥ 14	≥ 90

4. Results on joint drought - temperature conditions

A joint season classification of drought and temperature was therefore set for the seasons between 1981 and 2018, with a clustering analysis being applied using both K-Means and Generalized EM (Expectation Maximization) with similar results. The results for Generalized EM are plotted in Figure 2 confirming the adequacy of season categorization for drought and temperature. Cluster 1 represents wet to normal and cold to normal seasons, corresponding to seasons that are less likely to originate extreme forest fire occurrences. On the other side of the spectrum lies cluster 2, with hot or very hot and dry or very dry seasons, with a clear signal for 2005 and 2017 on the top right corner of the diagram. Clusters 3 and 4 represent a mix of conditions pulling in opposite directions in terms of conditions favouring forest fire occurrences. Therefore, cluster 3 aggregates dry or very dry seasons that are somehow compensated by cold to normal temperature regimes. On the other hand, cluster 4 aggregates hot to very hot seasons that are somehow compensated by wet to normal drought contexts.

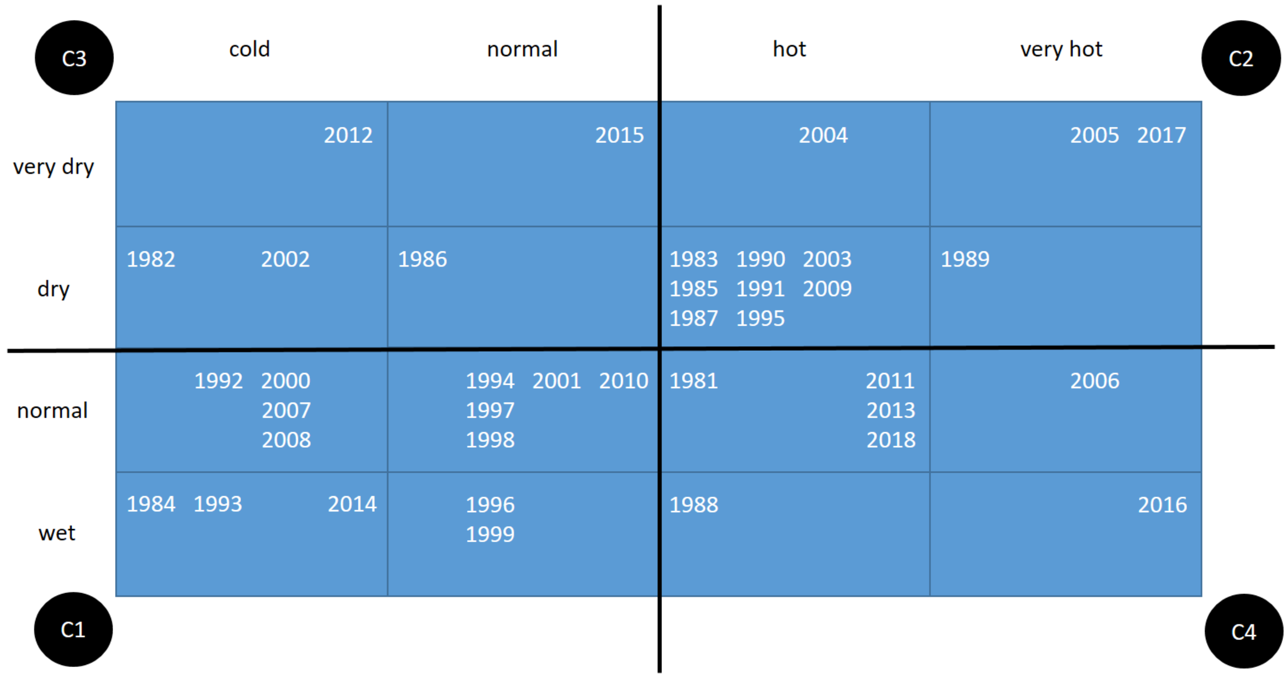

***Figure 2** – June to October season clusters (1 to 4) in the period 1981-2018 for a joint drought-temperature classification according to the scheme proposed by Tables 1 to 4 for mainland Portugal.*

5. Forest fire severity and pre-season drought conditions – a monthly approach

Despite the benefits of a seasonal analysis for drought and temperature for characterizing the fire season, it was found that seasonal forest fire indicators (occurrences and burned areas) were poorly correlated with pre-season drought indices (PDSI, SPI3 and SPI6) monthly values. Therefore, an additional lagged correlation analysis for NUT III was computed, but considering monthly forest fire indicators between June and October. For each NUT III, these monthly indicators were correlated with the monthly drought indices back to January, considering the 38 years of the dataset (1981-2018). A zero-lag correlation was also computed for determining the baseline.

6. Results on the relation between forest fire severity and drought

Figure 3 shows the baseline zero-lag correlation coefficient between monthly forest fire occurrences and monthly SPI3, PDSI and SPI6 drought indices from June to October at a NUT III level. Note that as drought is defined as negative in the drought indices, drought influence on forest fires will be defined as a negative correlation. The maps in Figure 3 show that, although drought conditions are important to characterize forest fire occurrences and burned areas, clearly other factors have to be taken into account. For example, even for SPI3 - the index that shows better zero-lag correlation results, along with higher statistical significance - the strongest negative correlation index was -0.739 (significant at 99% level) for *Beira Baixa* in June, which means that 54.7% (approximately half) of the variance in the number of occurrences in June is explained by the SPI3 drought index in June. For the majority of NUT III areas, the number of occurrences is generally more negatively correlated with drought indices in June, followed by October and then July. The stronger negative correlations (between -0.4 and -0.6, significant at least at 95% level) are essentially found in NUT III in the North and Centre of Portugal, showing that for these cases only 15 to 35% of the variance on the number of occurrences is explained by drought. Weaker negative (or even positive) correlations happen for August and September, meaning that the number of occurrences in those months shall be accounted for, in a larger proportion, by other factors. Similar patterns occur if burned areas are considered, but generally with lower and less significant correlations, nevertheless with PDSI and SPI3 indices performing better.

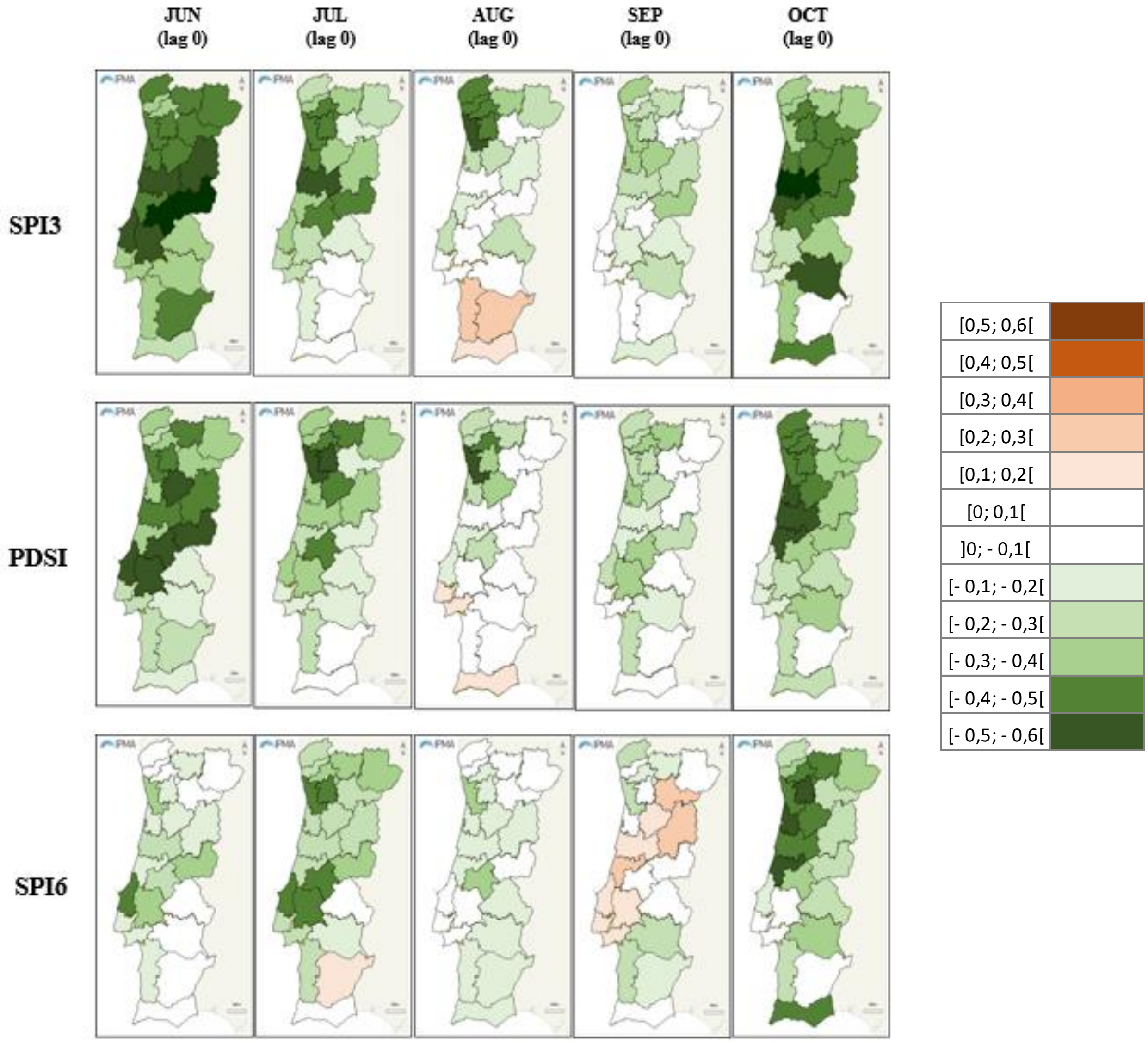

Figure 3 - Correlation coefficient between monthly forest fire occurrences and monthly SPI3 (upper row), PDSI (middle row) and SPI6 (lower row) drought indices from June (on the left) to October (on the right) at a NUT III level. Negative correlation in greenish shades and positive correlation in brownish shades.

It is clear that the negative correlation rapidly gets weaker with lags of 1, 2 or 3 months, even for the cases with stronger negative zero-lag correlation of drought with occurrences and burned areas (see Figure 4 for the case of July). Generally, correlations are not even significant at a 90% level with lags of 2 months or more. For lagged correlation SPI3 now seems to retain a weaker lagged correlation than PDSI (unlike zero-lag correlation). On the other hand, SPI3 seems to retain a higher lagged correlation than SPI6 for forest fire indicators in October, while the opposite happens for July, August and September.

Figure 4 shows that occurrences (also burned areas, not shown) in July for NUT III in the North and Centre of Portugal keep negative correlations of -0.3 to -0.5 (significant at least at a 90 % level) with the 3 drought indices in June and May, the signal being stronger for PDSI and SPI6. Even the strongest negative correlation with SPI6 in April (3 months' lag) for *Oeste* is only of -0.44 (20% of explained variance).

Figure 4 – Lagged correlation coefficient between forest fire occurrences in July and monthly SPI3 (upper row), PDSI (middle row) and SPI6 (lower row) drought indices from January (lag -6, on the left) to July (lag 0, on the right) at a NUT III level. Negative correlation in greenish shades and positive correlation in brownish shades.

Another relevant aspect is the relation between forest fires and wet pre-season regimes (positive values in drought indices) for some areas in the south of Portugal. Forest fire occurrences in *Alto Alentejo*, *Alentejo Central* or *Baixo Alentejo* in June and July (and also burned areas in June) are reasonably correlated with PDSI precipitation regimes in March, with correlation coefficients varying between +0.3 and +0.5 (10 to 25% of explained variance), significant at 90 or 95% level. For SPI3 and SPI6 correlations are lower and less significant, as partly showed in Figure 4 for July. In October, and also in *Alentejo Litoral*, occurrences and burned areas have correlation coefficients, statistically significant at 90 or 95%, between +0.27 and +0.45 (that is, at most 20% of explained variance), with wet regimes in months from January to July (not shown).

7. Final Remarks

Drought-Temperature data for mainland Portugal were jointly analysed in the period 1981-2018, both in a NUT III administrative aggregation and on grid point means. Results show seasons from June to October can be clustered in 4 groups according to monthly drought and temperature regimes. The proposed scheme may be used to compare a seasonal forecast with this database and find a better match in order to support seasonal forestry and forest fire management policies. The current study shows also that, regarding the relation between drought and the forest fire season, occurrences correlate better with drought than burned areas do. Zero-lag correlations are stronger (coefficient correlations of -0.4 to -0.6) in June and October, and in the North and Centre of Portugal, suggesting that other factors (such as the temperature/wind regime or human activity) have to be considered in the other months, namely August and September, and for the south of Portugal. Even for the cases of stronger correlation, pre-season drought conditions do not seem so preponderant, as monthly forest fire activity already has a lower correlation with drought conditions in the previous month, with no statistically significant correlation for more than the 2 previous months, at the most. On the other hand, for the south of Portugal wet regimes in March do explain up to 25% of the variance in forest fire occurrences in June and July (that is, 3 to 4 months ahead), while wet regimes between January and July also seem to explain up to 20% of the variance on forest fire occurrences in October. Finally, it should be noted that this study is based on a NUT

III administrative aggregation, which is in line with the 5 regional administrative domains currently considered in mainland Portugal for managing forest fire prevention and combat.

8. References

Cardoso, E., Moreira, N., Novo, I., Silva, P., Silva, P., Pires, V., 2022: Clusters analysis applied to drought and forest fires in mainland Portugal (NUT III) from 1980 to 2019. Submitted to the IX International Conference on Forest Fire Research, D. X. Viegas (Ed.).

ICNF, 2020: Incêndios Rurais – Estatísticas. Instituto da Conservação da Natureza e das Florestas (ICNF). Fire occurrence database. Available at: http://www2.icnf.pt/portal/florestas/dfci/inc/estat-sgif. [Accessed 26th March 2020].

Pires, V., Silva, A., Mendes, L., 2010: Drought Risk in Mainland Portugal. Rev. Territorium, 17(17):27-34., DOI:10.14195/1647-7723_17_3.

Pires, V., Cota, T., Silva, A., Santo, F., 2019: Drought Monitoring and Analysis in Mainland Portugal. Geophysical Research Abstracts, Vol 21. EGU General Assembly.

Silva, A.; De Lima, M.I. P., Espírito Santo, F., Pires, V., 2014: Assessing changes in drought/wetness episodes in drainage basins using the SPI. Die Bodenkultur - Journal for Land Management, Food and Environment; 12/2014; 65(3-4):31-37.