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LUÍS MÁRIO RIBEIRO

Evolution of the annual cycle of Burned Area in Portugal from 1980 to 2018: Implications for fire season management

Pedro Silva*[1]; Miguel Carmo[2]; João Rio[1]; Ilda Novo[1]

[1] *Departamento de Meteorologia e Geofísica, Instituto Português do Mar e da Atmosfera (IPMA, IP). Rua C do Aeroporto, Lisbon 1749-077, Portugal {pedro.silva, joao.rio, ilda.novo}@ipma.pt*
[2] *Institute of Contemporary History, NOVA University. Campus de Campolide, 1099-085 Lisboa, Portugal {miguelcarmo@fcsh.unl.pt}*

**Corresponding author*

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Abstract

The lengthening of the fire season in Portugal has been understudied although there is evidence of changes in recent decades. In this study, we have focused on the complete annual cycles of fire activity and meteorological fire danger, avoiding any subjective definition of what should mark the beginning and end of the fire season. Based on the daily time series of burned areas and number of active fires collected in mainland Portugal by state services from 1980 to 2018, we have searched for changes in the monthly and daily distributions. In particular, we developed an exceedance date method to determine day-scale trends in the anticipation/prolongation of fire activity in the year. An unequivocal increasing trend in the proportion of annual burned area between January and June was found, compensated by a diminishing trend in the proportion of burned area in the summer months (July to September). Apparently, the known secondary peak of fire activity in March played an important role in these changes that should be clarified in future analyses. Moreover, the daily analysis shows a clear shift of the cumulative burned area curves to the left, which suggests an anticipation of fire activity. The evolution of the 15% exceedance date, the annual date at which the threshold of 15% of the annual burned area is reached, shows a linear variation of -1.34 days per year in 1980-2018. In order to evaluate the meteorological contribution to this found anticipation of fire activity we used the Daily Severity Rating (DSR), from the Canadian Forest Fire Weather Index System, computed from the ECMWF ERA5 reanalysis. The results show a clear earlier growth of the DSR when comparing the averages for the first (1980-1999) and second (2000-2018) halves of the period. This divergence between the two curves rises steadily from the beginning of the second half of April to the end of September. Interestingly, a closer look shows a first increase in the DSR gap in March, which almost disappears in April before steadily increasing again until the beginning of October. Finally, we argue that up-to-date knowledge of interannual and interdecadal changes in the seasonality of both wildfires and fire weather is a decisive (though not the only) aspect for comprehensive fire season management.

1. The seasonality of fire in Portugal: a brief introduction

The incidence of wildfires throughout the year, represented by the number of occurrences and burned areas, shows an uneven pattern that derives from the annual cycles of temperature and precipitation and the corresponding cyclical dynamics of ecosystems (e.g. Kwiecien et al. 2021, Viegas & Viegas 1994). This relationship between climate and fire seasonality is well embodied in the weather fire risk indices – as well exemplified by the FWI and its long memory drought subindices (Van Wagner 1974, Carmo et al. 2021) – and has received renewed attention in recent decades in the context of concomitant changes in climate and fire regimes. The focus on 'the lengthening of the fire season' in a changing climate has in Wotton and Flannigan (1993) one of the first studies and has been increasingly studied in the last few years (Jain et al. 2018, Westerling 2016, Salloum & Mitri 2014, UNEP 2022).

The present study fits these concerns and research framework aiming (i) to identify relevant changes in the annual cycle of fire activity in mainland Portugal, based on the extensive records of fire occurrences in the period 1980-2018 (≥1.0 hectare) and some previous results (cf. Carmo et al. 2021), (ii) to evaluate the meteorological contribution using the Daily Severity Rating (DSR) (Van Wagner 1987) and, finally, (iii) to discuss the interannual and interdecadal variation in wildfire seasonality in the context of fire management and the operational definition of 'fire season'.

On this last point, we must note that contemporary fire regimes are affected by human activities. Fire seasonality is conditioned not only by climatic and ecological forcings, but also by *unnatural* annual cycles of ignitions, fuel availability, as well as changes in fire suppression approaches and means, which have specific calendars themselves changeable over time. See, for example, the secondary peak of fires in March, identified in northwestern Iberia (da Câmara et al. 2014) and in our nationwide 1980-2018 data (both in number of occurrences and burned areas, data not shown), which is associated with the (inseparable) combination of early spring agricultural practices and a recurrent window of weather conditions conducive to fire spread.

The monthly distribution of the annual burned area in Portugal in the period 1980-2018 shows a broad concentration in July, August and September (which represents on average 82.5% of the total burned area each year) (Figure 1). However, this monthly data also shows an increasing fraction of the annual burned area occurring outside those three summer months (Figure 2). In fact, there is a meaningful increase in the fraction corresponding to the months of January to June, while the fraction of July to September shows a decreasing trend (Mann-Kendall tests with $\rho<0.01$).

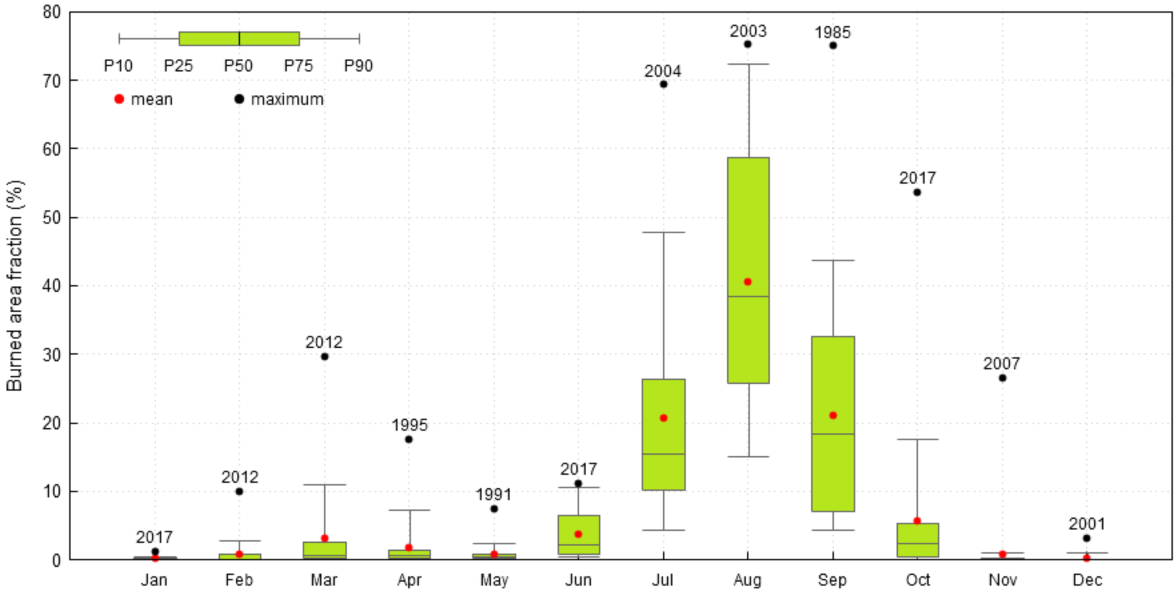

Figure 1: Monthly distribution of the annual burned area in the period 1980 to 2018, indicating the 10th, 25th, 50th, 75th and 90th percentiles (box-and-whisker plot), the mean (red dots) and the maximum monthly values (black dots labeled with the year of occurrence).

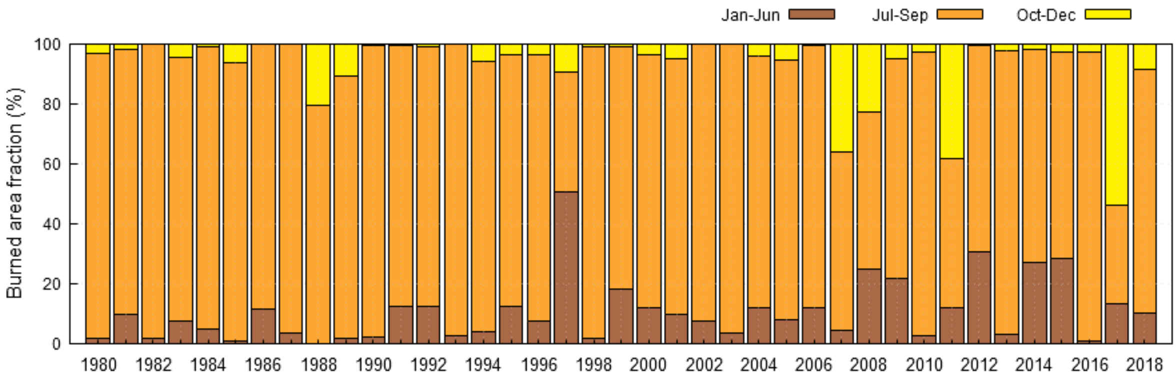

Figure 2: Distribution of the fraction of annual burned area occurred before (Jan-Jun months, brown bars), during (Jul-Set, orange bars), and after (Oct-Dec, yellow bars) the most critical months in wildfires incidence in the period 1980-2018.

2. Evolution of the burned area throughout the year: is the fire season getting longer?

The year 2017 sounded several alarm bells in Portugal: beyond the sad and unprecedented figure of 117 deaths caused by wildfires and a burnt extent never before recorded (about 540,000 ha), the two main fire events occurred before (17-22 June) and after (15-17 October) the official fire season window decreed by the

Portuguese authorities (Turco et al. 2019, Viegas et al. 2017, 2019). In 2017, 67.1% of the burned area did not occur in the three summer months (Jul-Sep, see Figure 2). To better understand the historical evolution of the annual fire cycle, we have used a simple method of determining for each year the dates (annual Julian day) at which the fractions of the annual burned area, in increments of 1%, are reached. This exceedance date method allows us to compute the annual trends for each single fraction and evaluate their statistical significance and as the advantage of being insensitive to the severity of fires in a particular year.

The two-decade averages represented by the color lines in Figure 3 show that, in the last two decades, the fractions of burned area between 1% and close to 30% are being reached earlier in the year. This suggests a widening of the annual cycle with displacement of the left tail of the burned area distribution, as a likely result of the anticipation of fire activity in the year. Trend analysis confirms the significance of early exceedance dates up to the 16% fraction (Mann-Kendall test, $\rho<0.05$). The remaining exceedance dates, including the slowing down phase of the fire cycle in late summer, show no significant trends. There was a 27-day (at the 10% exceedance dates) and 23-day (at the 16% dates) move back comparing the first and the second half-period averages. Considering the 15% fraction as a reasonable indicator of the beginning of the fire season, we obtained an anticipation linear rate of 1.34 days per year (Figure 4).

These results are in line with the expected lengthening of the fire season in Portugal during the 21st century, as detailed in Moriondo et al. (2006) and Carvalho et al. (2010). These two studies also identified a clearer signal in the fire season earliness compared to its extension into autumn. Similar trends have been obtained in the southwestern USA for recent decades, based on both fire activity (Westerling 2016) and fire weather risk (Jain et al. 2018).

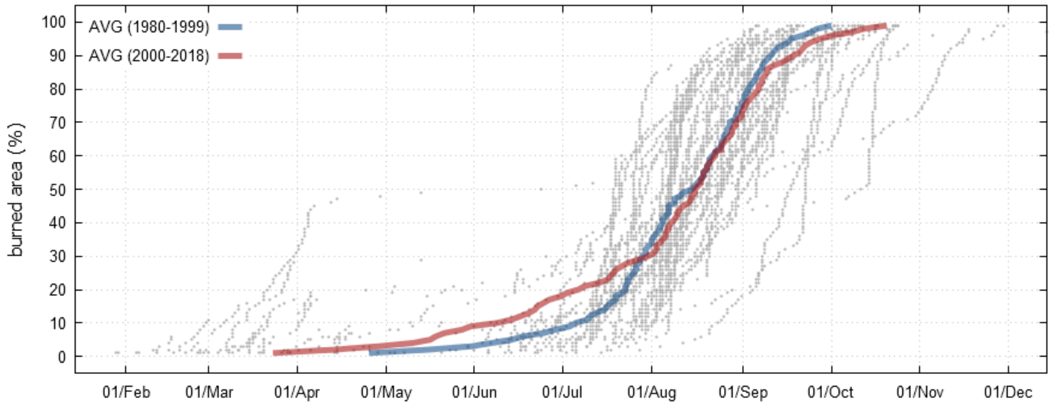

Figure 3: Exceeding dates for successive fractions (1%, …, 99%) of the total annual burned area in each year from 1980 to 2018. The grey dots represent the 39 annual dates for each fraction. The color lines represent the average dates for the first (1980-1999, blue line) and the second half (2000-2018, red line) of the period.

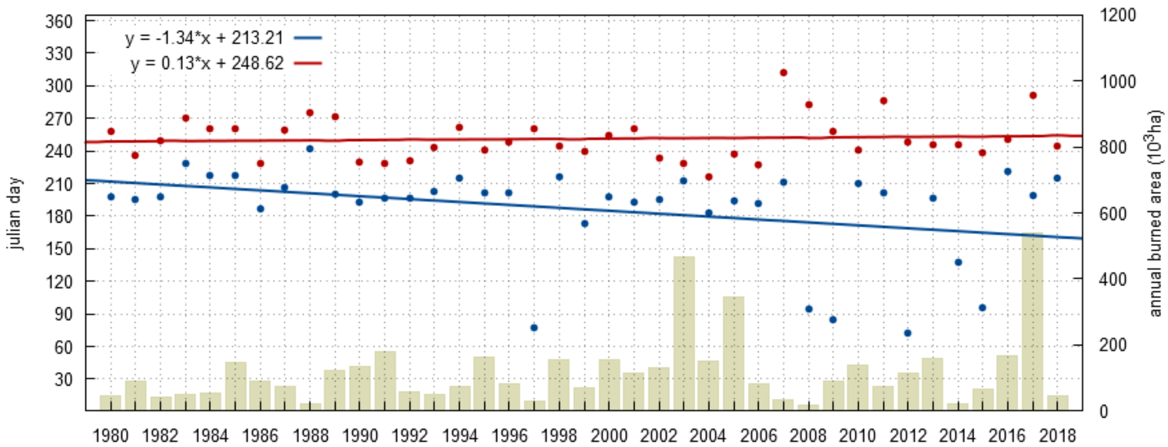

Figure 4: Evolution of the dates on which the 15% (blue points) and 85% (red points) of the total annual burned area are exceeded in the period 1980-2018, and corresponding adjusted linear regressions. The grey bars show the annual burned areas. The correlation between the 15% exceedance dates and the annual burned area is weak (r = 0.18).

3. The meteorological perspective: DSR patterns in the period 1980-2018

Changes in the annual fire cycle are related, in varying ways and intensity, to changes in atmospheric conditions conducive to fire onset and spread (e.g. Flannigan & Wotton 2001, Gouveia et al. 2016, Ruffault et al. 2018). Regarding wildfire seasonality, this relationship can be investigated with the DSR, Daily Severity Rating, which has a regular use in Portugal in the monitoring of the fire weather risk build-up throughout the year. DSR is an extension of the FWI system that transforms daily FWI values through a power expression (higher FWI values are thus emphasised) (Van Wagner 1987). In the present analysis we computed the annual cumulative DSR series, starting on January 1st, with data provided by the ERA5 reanalysis (Vitolo et al. 2020, CEMS 2019) on a grid of 163 points over mainland Portugal for 1980-2018.

Figure 5a shows the two mean cumulative DSR curves for the first (1980-1999) and second (2000-2018) halves of the study period. An increasing departure of the two curves is observed starting around April to the end of September. If we look closely at the difference between the two periods (in Figure 5b), we see a slight growth in the DSR difference as early as March, which then reduces to nearly zero in April before steadily increasing again. Considering the aforementioned secondary peak of fire activity and risk in March, this slight difference may represent a historical accentuation of that peak. In interpreting these results, we must take into account that the DSR is a good indicator of the 'sum' of fire-related weather conditions and that we are comparing average values over Portugal.

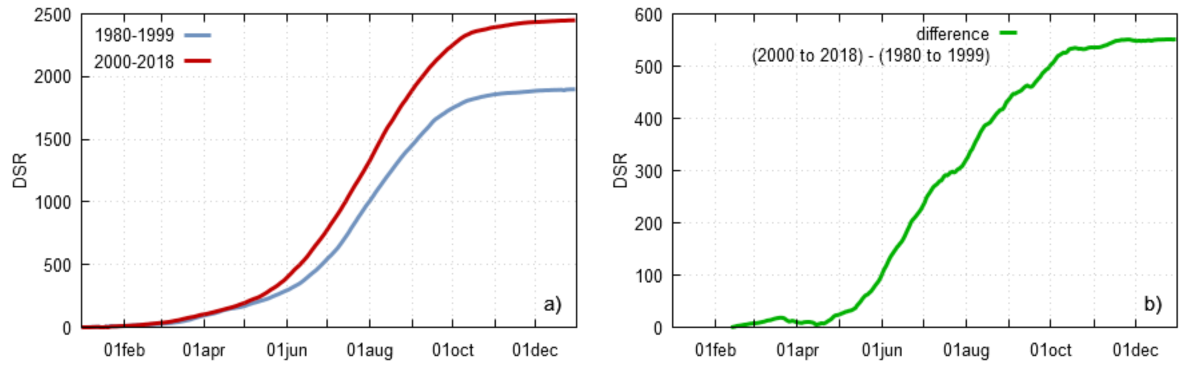

***Figure 5:** (a) Mean cumulative DSR values in the first (1980-1999, blue curve) and second half (2000-2019, red curve) of the study period. The DSR is cumulated daily from 1 January to 31 December in each year. (b) Daily difference between the two periods average (1980-1999 and 2000-2018); the scale on the Y-axis was changed.*

4. Conclusions: Linking fire-weather and fire season management

The results presented show with confidence that the distribution of burned area has been moving progressively out of the critical period from July to September. This change is more evident during the spring period, which may be due to the combination of several factors, such as variations in human activities, in the type of machinery used in fields, in the agricultural and grazing cycles, among others, including necessarily changes in weather conditions on the scale of years and decades. Isolating social, ecological and climatic factors could be an arduous task. A good illustration of the interdependence between these factors is that the annual, operational definition of fire season, based on fire weather indicators, affects the distribution of ignitions by shifting restricted uses of fire and other fire-risk activities to the months preceding the 'season'.

The cumulative DSR showed a faster growth from the end of April when comparing the pre- and post-2000 periods, from which a direct contribution of meteorology can be deduced in the extension of the fire cycle in Portugal since 1980. This early growth must be evaluated in greater detail, both in the temporal and spatial components, in order to assess variations in the frequency of FWI values above specific thresholds and in the regional distribution of fire danger. Furthermore, the effect of March on the early season will need to be clarified, as the burned area series for this month confirms an upward trend (Mann-Kendall, $\rho < 0.01$) that does not occur in neighbouring months.

In 2017, as mentioned, 67.1% of the burned area occurred outside the 'fire season' or 'critical fire period', as legally defined by the Portuguese authorities. The term 'critical period' has gained current use since 2004, when it replaced in legal framework the 'normal fire season', which had been established in 1981. The legal definition of the season window changed almost every year, recording the earliest beginning on May 1st (e.g. 1995) and latest ending on October 31st (e.g. 1988 and 2011). 2017 has weakened the operational role that the fixed period has had until then, in favour of greater focus on short-term forecasting of weather fire risk. We should note however that the fixed definition of 'season' included since 1981 the possibility of declaring extraordinary periods, 'when meteorological conditions that justify it occur or are expected'. This assessment was at the time based on a daily risk index given by the Angström formula (Fernandes 2015, Lourenço 1988, Decreto Regulamentar n.º 55/1981, Portaria n.º 167/2016, Portaria n.º 195/2017).

From a management point of view the seasonality of fires in mainland Portugal – presenting a well-known interannual and also decadal or climatic variability, as seen in recent decades – must be conciliated with the social and political definition of the fire season, on which numerous activities in rural areas depend.

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