Science of the Total Environment 559 (2016) 151–165

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Space-time clustering analysis of wildfires: The influence of dataset characteristics, fire prevention policy decisions, weather and climate

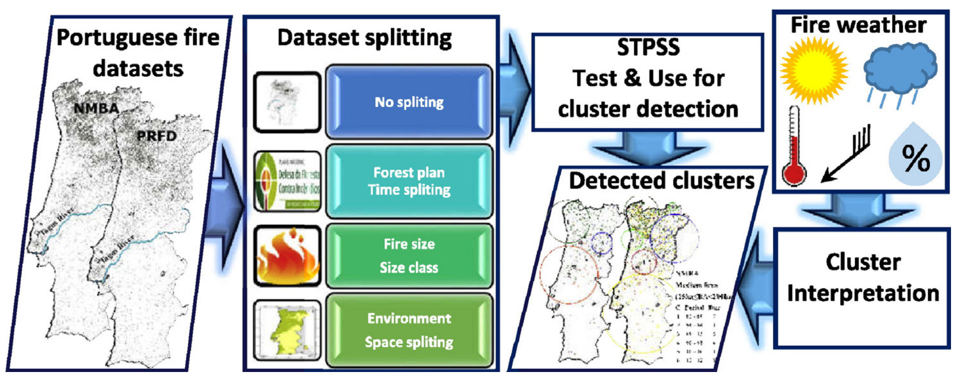
Joana Parente [a], Mário G. Pereira [a,b,*], Marj Tonini [c]

[a] Centre for Research and Technology of Agro-Environment and Biological Sciences, CITAB, University of Trás-os-Montes and Alto Douro, UTAD, Quinta de Prados, 5000-801 Vila Real, Portugal
[b] Instituto Dom Luiz, IDL, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, Edifício C8, Piso 3, 1749-016, Lisboa, Portugal
[c] Institute of Earth Surface Dynamics (IDYST), University of Lausanne, 1015 Lausanne, Switzerland

HIGHLIGHTS

- Spatial-temporal scan statistics were applied to different Portuguese fire datasets.
- Results depend on the dataset and discrepancies are bigger for small fires.
- Two fire regimes were found (North vs South) due to different environmental factors.
- Detected clusters were discussed in terms of fire weather and fire management.
- Abnormal weather conditions were associated to clusters of all fire size classes.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 26 January 2016
Received in revised form 17 March 2016
Accepted 18 March 2016
Available online xxxx

Editor: D. Barcelo

Keywords:
Forest fires
Space-time permutation scan statistics
Cluster analysis
Weather
Climate

ABSTRACT

The present study focuses on the dependence of the space–time permutation scan statistics (STPSS) (1) on the input database's characteristics and (2) on the use of this methodology to assess changes on the fire regime due to different type of climate and fire management activities. Based on the very strong relationship between weather and the fire incidence in Portugal, the detected clusters will be interpreted in terms of the atmospheric conditions. Apart from being the country most affected by the fires in the European context, Portugal meets all the conditions required to carry out this study, namely: (i) two long and comprehensive official datasets, i.e. the Portuguese Rural Fire Database (PRFD) and the National Mapping Burnt Areas (NMBA), respectively based on ground and satellite measurements; (ii) the two types of climate (Csb in the north and Csa in the south) that characterizes the Mediterranean basin regions most affected by the fires also divide the mainland Portuguese area; and, (iii) the national plan for the defence of forest against fires was approved a decade ago and it is now reasonable to assess its impacts. Results confirmed (1) the influence of the dataset's characteristics on the detected clusters, (2) the existence of two different fire regimes in the country promoted by the different types of climate, (3) the positive impacts of the fire prevention policy decisions and (4) the ability of the STPSS to correctly identify clusters, regarding their number, location, and space-time size in spite of eventual space and/or time splits of the datasets. Finally, the role of the weather on days when clustered fires were active was confirmed for the classes of small, medium and large fires.

* Corresponding author at: Universidade de Trás-os-Montes e Alto Douro, Quinta de Prados, 5000-801 Vila Real, Portugal.
E-mail addresses: joaparente@gmail.com (J. Parente), gpereira@utad.pt (M.G. Pereira), marj.tonini@unil.ch (M. Tonini).

http://dx.doi.org/10.1016/j.scitotenv.2016.03.129
0048-9697/

1. Introduction

Fire is a fundamental earth system process acting at global scale and playing an essential dynamic role in terrestrial, aquatic and atmospheric systems (Bedia et al., 2014; Jolly et al., 2015). There are many adaptations of ecosystems to fire as well as several fire prone or resistant species (Kozlowski, 2012; Van Wilgen et al., 2012). Nevertheless, fire has a profound impact on, soil, vegetation structure and functioning, surface albedo, water availability and quality, air pollution and human health, terrestrial and aquatic ecosystems and it is also the cause of human casualties and significant ecological and economic losses (Barbati et al., 2010; Bedia et al., 2014; Hedo et al., 2015; Jolly et al., 2015; Kozlowski, 2012; Migliavacca et al., 2013; Pereira et al., 2016; Santos et al., 2015a; Santos et al., 2015b).

The magnitude of this phenomenon and its consequences strongly depend on several human and natural factors including socioeconomic activities, land management practices, topography, vegetation cover, weather and climate (Costa et al., 2011; Pereira et al., 2014a; Pereira et al., 2013; Trigo et al., 2006; Venäläinen et al., 2014). Weather has a deep influence, directly and indirectly, on fire ignition potential, fire behaviour, fire severity and fire extinction, by promoting the radiative and convective heat transfer, increasing the dryness and flammability of the fuels and supplying oxygen to the combustion zone (Benson et al., 2008; Migliavacca et al., 2013; Morvan and Dupuy, 2004; Pereira et al., 2013; Pereira et al., 2005; Trigo et al., 2013; Venäläinen et al., 2014). Therefore it is not surprising that high fire activity is associated to anomalous atmospheric conditions and circulation patterns (Amraoui et al., 2015; Pereira et al., 2005) and burnt area (hereafter, BA) models used weather and climatic parameters as predictors (Flannigan et al., 2000; Pereira et al., 2013; Sousa et al., 2015; Trigo et al., 2013).

On the other hand and at longer time scales, climate aids to define the fire activity/danger season characteristics (Flannigan et al., 2000; Wotton and Flannigan, 1993) and the fire management activities such as fire bans, fire restrictions, prescribed burns (Flannigan et al., 2009; Spittlehouse and Stewart, 2004). The temperate type of climate of the Mediterranean basin, with rainy and mild winters followed by warm and dry summers, helps to explain/understand why this region is especially prone to the occurrence of a large number of summer fire events and the monthly BA present a prominent annual cycle (Pereira et al., 2011b; Pereira, 2015). Actually, Spain and Portugal (the Iberian Peninsula) account for >50% of the fires registered in Europe, with most of the fire events occurring in the summer (May to October) period (Pereira et al., 2014a). Between 1980 and 2013, $>600 \times 10^3$ fires burned a total area of 3.72×10^6 ha of the Portuguese forested surface, which represents about 70% of the country forest land area and making of Portugal the European country with the highest forest fires density and percentage of area burnt among southern European countries (Catry et al., 2010; Pereira et al., 2011b; Pereira et al., 2014a; Tedim et al., 2015).

For these reasons, it is fundamental a better knowledge of the fire regime in order to support the fire prevention, detection, suppression, fight and management activities (Bergeron et al., 2002). Far from being uniform, the spatial and temporal distributions of the fires exhibit grouping patterns regardless of their size (Pereira and Turkman, 2011; Telesca, 2007), whose characteristics and causes are important to know in greater depth. On this respect, Pereira et al. (2015) recently tested the reliability of the space-time permutation scan statistics (STPSS) as a local clustering method to detect real clusters for different fire size classes (with BA above 0.1, 1.0, 10.0 and 100 ha) and using maximum scanning window size of different dimensions. They found, for small and medium size fires, a similar small number of relatively large size space-time statistically significant clusters over the northern region while, for the large fires (BA ≥ 100 ha), a relatively higher number of smaller temporal size clusters wide spread over the entire country area. Furthermore, when the size of fires increases, the clusters' location tends to displace from the west coast to inland regions far less populated but more forested and with rougher relief, which inspired the characterization of the detected clusters in terms of specific landscape characteristics (i.e., land cover and topographic) as well as socio-economic features (population density and urban vs rural land use) of the areas covered by the detected clusters. However, in spite of recognising the fundamental role of the weather on the fire activity in Portugal (Carvalho et al., 2008; Pereira et al., 2005), in particular the triggering effect of sporadic short term extreme weather events (e.g., heatwaves) on the occurrence of large fires (Trigo et al., 2006), which are responsible for the large majority of the burnt area in Portugal, the detected clusters were not characterized in terms of the fire weather.

Actually, Portugal has two very different official observed fire databases, namely the National Mapping Burnt Areas (NMBA) and the Portuguese Rural Fire Database (PRFD). These two datasets have substantially different characteristics respecting their nature, spatial and temporal resolution. The PRFD is based on ground measurements, while NMBA is based on the analysis of satellite imagery. Accordingly, the two databases are used indiscriminately but independently by the researchers that specifically select them based on their best features for the type of analysis they intend to perform. (e.g., Moreira et al., 2010; Pereira et al., 2011b; Pereira et al., 2015; Tedim et al., 2015). Thus, it is important to compare these two databases regarding the existence and characteristics of space-time clustering patterns.

After the exceptional fire seasons of 2003 and 2005, when the total burnt area reached, respectively, circa 450,000 and 350,000 ha, the Portuguese Government recognized fires as serious menace to Portuguese forests, which threatens the economic and social sustainability of the country, assumed the forest protection as a priority and, in the Resolution of the Council of Ministers no. 65/2006, approved the national plan for the defence of forest against fires (*Plano Nacional de Defesa da Floresta Contra Incêndios*, PNDFCI), to foster active forest management and create favourable conditions for the progressive reduction of forest fires. The PNDFCI defines the objectives, strategy, priorities and an articulated and structured implementation of a set of actions in five strategic areas of action: (i) increasing the resilience of the territory to forest fires; (ii) reducing the incidence of fires; (iii) improving the efficiency of fire attack and management; (iv) recover and rehabilitate the ecosystems; and, (v) adaptation of an effective organizational and functional structure. The PNDFCI assumes the time periods of 2006–2012 and 2012–2018 for the development of sectoral policies and the achievement of actions and objectives.

Therefore, in summary, the aims of this study are: (i) to assess the influence of dataset's characteristics on the detection of clusters of fire events in Portugal using STPSS method; (ii) to identify and characterize the atmospheric conditions associated with the fires belonging to each detected clusters; (iii) to assess the existence of two different fire regimes in Portugal driven by climate contrasts based on the great similarity between the spatial distribution of the forest fires in Portugal, with much higher density in the northern than in the southern halves (Pereira et al., 2011b), and the climate classification pattern (Peel et al., 2007); and, (iv) to use space-time permutation scan statistics to assess changes in the fire regime, particularly in the clustering patterns, due to climate and fire prevention policy decisions, namely those associated with the implementation of PNDFCI.

2. Materials: study area characterization and analysed datasets

2.1. Study area

Mainland Portugal (37°N and 42°N latitude and 6°W and 10°W longitude) has a total land area of 89,000 km^2 and the altitude range from sea level in the western and southern coast to about 2000 m, in the *Serra da Estrela*, located in the north central region (Moreira et al., 2010). The mean annual air temperature ranges from 7 to 18°C following a NW-SE gradient and the annual rainfall span from 400 mm to 2800 mm, with