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DOMINGOS XAVIER VIEGAS

LUÍS MÁRIO RIBEIRO

Wildfire rate of spread according to fire isochrones and wind direction in four of the 2019-2020 Black Summer Fires in Australia

Andrea Duane[1,2]*; Mercedes Bachfisher[3]; Lluís Brotons[4]; Marc Castellnou[5]

[1]*Department of Agriculture and Forest Engineering (EAGROF), University of Lleida, Av. Alcalde Rovira Roure 191, 25198 Lleida, Spain. {andreaduane@gmail.com}*
[2] *Forest Science Centre of Catalonia (CTFC), Carretera vella de Sant Llorenç de Morunys km 2, 25280 Solsona, Lleida, Spain*
[3] *The Emergency Program, Calle Ignasi Barraquer Nº4, 08460, Santa Maria de Palautordera, Barcelona, Spain. {mercedes.bachfischer@gmail.com}*
[4] *CREAF, Edifici C. Autonomous University of Barcelona. 08193 Bellaterra, Barcelona, Spain.{lluis.brotons@gmail.com}*
[5] *GRAF division, Catalan Fire and Rescue Service, Carretera Unversitat Autonoma s/n, 08290 Cerdanyola del Vallès, Spain. {incendi@yahoo.es}*

**Corresponding author*

Keywords

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Abstract

Wildfires of recent years are unprecedented in terms of fire behavior and impacts all around the world. The wildfire community still needs to better comprehend the physics behind the phenomenon to reduce uncertainty and increase the response capacity during emergencies. Studying past fires becomes crucial for predicting future fire behaviors. However, often the description of fire behavior in past fires has been associated with a high degree of subjectivity according to responders' description. Here, we offer a new tool that enables the user to calculate the maximum rate of spread of wildfires according to an isochrones map of the fire. In addition, it includes the possibility to calculate this maximum rate of spread according to wind direction. We apply it to a set of four fires that occurred between the 29 and 31st December 2019 in Australia. We believe this can be a very useful tool for fire analysts to compare and analyze past fires and increase our global understanding of fire behavior.

1. Introduction

Wildfires of recent years are unprecedented in terms of fire behavior and impacts all around the world (Duane, Castellnou, and Brotons 2021). The wildfire community still needs to better comprehend the physics behind the phenomenon to reduce uncertainty and increase the response capacity during emergencies (Castellnou et al. 2019). Studying past fires is a crucial step for evaluating wildfire behavior, understanding the mechanisms and providing new theories for fire spread.

Current fire behavior research is based both on mathematical spread models and on witnessed evidence on wildfire spread. While the first one has a wide range of possibilities for analyzing fires, the latter has been mostly based on laboratory experiments. However, the observations in wildland fires differ far away from what has been traditionally observed during wildfires.

Reports on wildfires have always informed very important data about fire behavior, but that has been difficult to systematically collect, or liable to a high degree of subjectivity. Many studies and reports have published values for rate of spread, one of the most important variables that explain fire behavior. These values, although useful, become difficult to compare because of a lack of an objective method to calculate it. Although the literature has reported a rate of spread of about 33 km/h in grassland fires (Cruz et al. 2015), fires spreading at a 1 km/h are already above the suppression capacity for firefighters. The limit of 3 km/h has been proposed to define an extreme wildfire event (Scott and Burgan 2005; Tedim et al. 2018).

In this study, we present an algorithm that allows the user to calculate the maximum rate of spread of a wildland fire according to a map of isochrones of wildfire growth. With this new tool, we allow the scientific community to objectively compare the observed fire behavior of different fires and relate such information with the appropriate data to derive new knowledge on fire mechanisms.

More specifically, we apply the tool to a set of wildfires that occurred during the black summer 2019-2020 season in Australia.

2. Methods

2.1. Algorithm

The algorithm presented here is currently in the publication process. However, we provide some general traits that can help to understand the potentiality of the tool.

The goal of the algorithm is to provide a maximum distance run by the fire in a certain period according to wildfire isochrones. However, the potential also relies on the fact that this distance can be calculated according to the shape of the isochrones exclusively, or by following wind direction (+-5º) at the moment of the fire interval period. In case the polygon of a fire return interval contains unburnt areas in that fire interval period (i.e. "holes"), the algorithm assumes that the fire has had the capability to jump these areas in its maximum run.

The basic information required to run the algorithm are the isochron map (polygon file type) and a wind direction table associated with each interval. The algorithm is built in R (R Core Team 2021).

2.2. Selection of fires

We selected four that fires occurred in the region between Victoria and New South Wales on the days 29-30 and 31 December 2019 (Table 1). They all occurred in similar weather and drought conditions, and they affected areas with similar vegetation types.

Table 1- Characteristics of selected fires

Fire	Country	Region	Initial Date	Final Date (imagery based)	Total Burnt Area (ha)
1- Green Valley Talmalmo	Australia	NSW	31/12/2019	15/01/2020	471,398
2- Wadbilliga	Australia	NSW	29/12/2019	05/02/2020	373,246
3- East Gippsland – Goongerah	Australia	Victoria	30/12/2019	07/02/2020	645,618
4- East Gippsland – Mallacoota	Australia	Victoria	30/12/2019	07/02/2020	363,233

It is important to notice that the two Gippsland fires shared boundaries after a while of their beginning. However, since we aim at studying the behavior of fire and thus capturing the direction is important, we have considered both fires distinct fires four our propagation analysis.

2.3. Isochrones

We positioned fire fronts (isochrones) for each fire according to the hotspots reported by the VIIRS and MODIS sensors (Schroeder et al. 2014), building a VIIRS fire perimeter (polygon) using a minimum bounding geometry. We supported such polygons with Sentinel-2 and Landsat 5,6,7, and 8 images (we used whatever image was available for each fire interval period. The goal of these supporting images was to check the consistency of the delimitation made by the VIIRS sensor). The fire interval periods lasted between 11 and 13 hours, according to the VIIRS revisit time.

2.4. Weather data

We used hourly weather data provided by the Copernicus Data Store, specifically the reanalysis ERA5 hourly pressure dataset downscaled at 0.25º resolution. Data included the two components of wind (U,V) at 10 meters, from which we calculated wind direction.

3. Results

We calculated maximum runs according to the shape of the isochrones (Figure 1) and according to the wind direction and the shape of the isochrones (Figure 2).

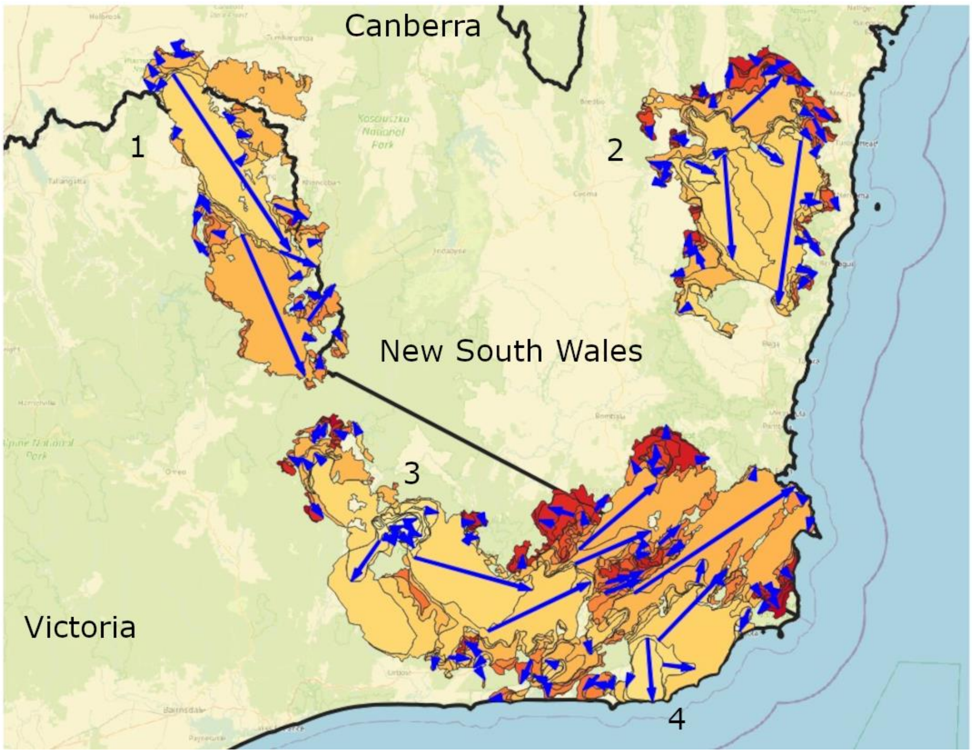

Figure 1. Maximum fire runs (blue arrows) according to the isochrone shape in the four major fires analyzed in Southeastern Australia. The Goongerah and Mallacota fires seem a single one because they share boundaries, but they are considered two different starting ignitions.

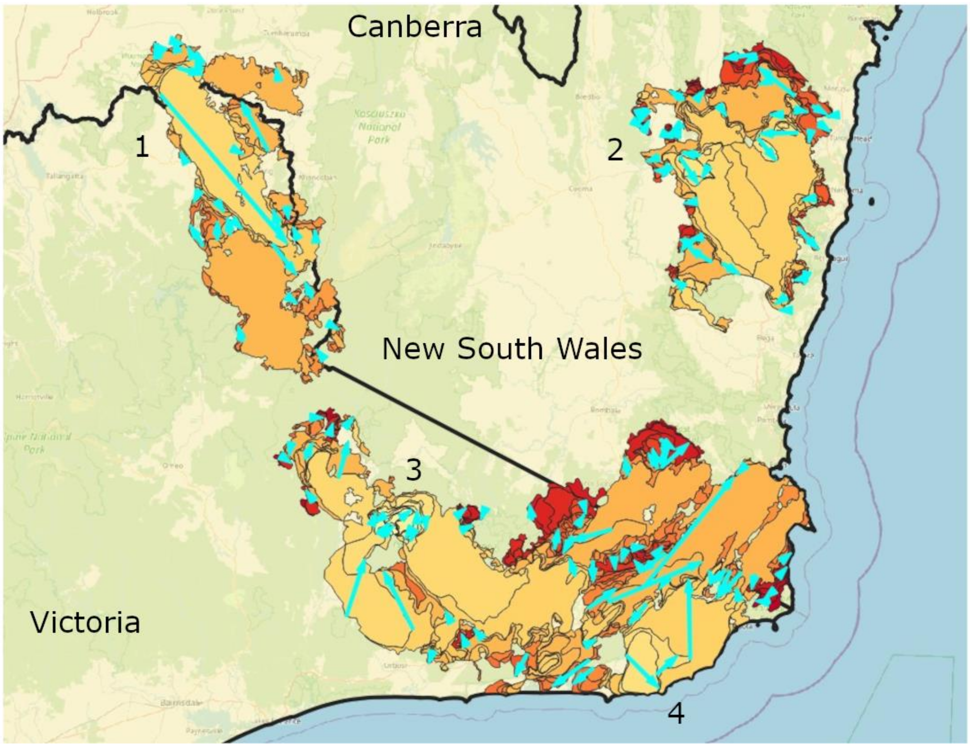

Figure 2. Maximum fire runs (light blue arrows) according to the wind direction and the isochrone shape in the four major fires analyzed in Southeastern Australia. The Goongerah and Mallacota fires seem a single one because they share boundaries, but they are considered two different starting ignitions.

We found that the most rapid fire runs where usually detected using only the shape of the isochrones (Figure 3). Maximum runs were calculated at around 6 km/h, being the fastest run in this analysis a run that took place in the Talmalmo fire on the 31st of December 2019 at 01:00 am, running at 6.535 km/h. However, when considering the total amount of runs, the average was usually higher when using the shape of the isochrones together with wind direction, although the differences where not significant (Figure 3). However, a paired analysis has not been considered in the present paper. Importantly, although the average speed was not very high when considering all runs (around 0.65 km/h), there were 21 runs exceeding the 1 km/h threshold, which can be considered a limit in fire suppression capacity. In addition, these 21 runs occurred mostly between the 31st of December 2019 and 5th of January 2020 and occurred in the four analyzed wildfires.

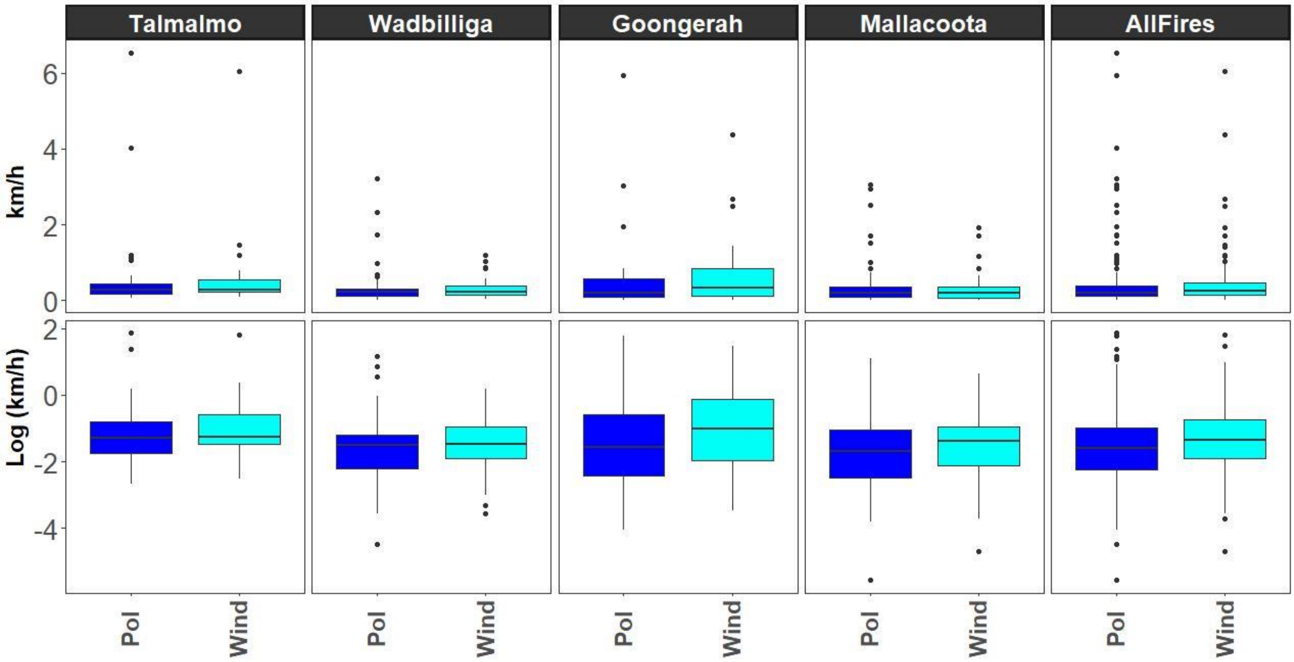

Figure 3. Maximum fire runs in each fire and considering all fires together. The upper panels show the actual values, whereas the lower panel show the logarithmic transformation to better appreciate the bulk of the data. Dark blue boxplots represent runs according to the shape of the isochrones ("pol"), whereas light blue boxplots according to the wind direction and the isochrone shape ("wind").

4. Discussions

We present the application of a new algorithm in a set of four wildfires that occurred in Australia during the black summer 2019-2020 season. The algorithm provided insightful results about fire rate of spread in these extreme fires. First of all, we detected very fast runs in the four fires: the maximum run reached 6.5 km/h in the Talmalmo fire. This is a very fast run for a forest fire: while in grass fires some rates of spread have been monitored at more than 30 km/h (Cruz et al 2015), in forest fires few runs exceed the 6 km/h threshold, only few of them in Eucalypt forests of Australia (Cruz et al 2020). Alexander and Cruz 2006 reported a 6.42 km/h fire in coniferous forests of Canada. We also obtained that a number of fire runs spread at more than 3 km/h (threshold to considered extreme), and several spread at more than 1 km/h, the limit of direct fire suppression. This indicates that the episode lived in Australia during the occurrence of these four fires was of extreme gravity given the fire behavior reported.

Our algorithm was able to calculate two different rates of spread for the same fire interval: according to the shape of the isochrones and according to the wind direction. In Figure 3 we compared both sets of results and we could see that there are not big differences between both ways of calculating rate of spread: while the major runs where always reported when considering only the shape of the isochrones, the average was higher when considering the wind direction. However, differences were not significative. It is important no notice that a "per pair" analyses would allow to obtain if per each run, the wind direction calculation gives larger or smaller rates of spread, because having all runs together does not allow to differentiate per each run.

Having a standard and homogenous way to report fire of spread opens the possibility to develop more in deep science about the factors behind fire behavior in a more general and objective way. We believe this is a simple exercise but can have a great potentially in applying it at different fires in which the progression of the fire is available.

The algorithm does not inform about the possible path of the fire inside the fire interval period, as this information is not derivative from the isochrones. The fire can change its direction because of wind direction changes in that time span, new slopes in different directions, interaction between wind and topography (Sharples et al. 2011), erratic atmospheric winds due to unstable atmospheres, fire suppression forces re-adjustments (back-fire), etc. But our analysis considers only straightforward runs as they represent the minimum distance travelled by the fire at least in that time (it might have gone faster, but we have no evidence). However, including wind direction in its calculation is an added value that can help to understand observed rate of spread and explain some of the behaviors that firefighters often report but that until now were not objectively measurable.

In this study, neither the fuel type, amount nor humidity, have been included. Although the objective was not to predict rate of spread rather than calculate the observations, we believe that mixing this type of data with other explanatory variables could increase the understanding of fire spread. By the obtainment of the rate of spread of past fires one can also analyze the spatio-temporal patterns of extreme runs around the world. For instance, the moment of the maximum rate of spread. It is commonly assumed that maximum rate of spread happens at the beginning of the afternoon, when temperature is maximum, relative humidity is minimum, and local winds and breezes achieve their maximum speed (van Wagner 1987). But recent extreme fires put into question this pattern: the Pedrogao Grande Fire occurred in June 2017 in Portugal reported an extreme run of 5.7 km/h at 20:00 hour local time (CTI 2017) generating a very serious civil entrapment with 64 fatalities. In the black summer season 2019-2020 in Australia, many of the pyrocumulonimbus events and their massive spread were reported at night (Peterson et al. 2021). At the same time, this analysis can help to disentangle the relation between fire spread direction, fire front, general wind, and many other spatial patterns of the fire.

Having an objective way of calculating rate of spread will likely help to understand wildfire behavior around the globe. This will ultimately help to develop appropriate prevention measures to diminish fire of spread and the negative impacts of wildfires.

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