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Natural Hazards and Earth System Sciences
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Discussions

# *Interactive comment on* "Using cellular automata to simulate wildfire propagation and to assist in fire prevention and fighting" *by* Joana G. Freire and Carlos C. DaCamara

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The authors thank Referee #1 for his very constructive comments.

1. The paper is well structured and well written. However, I would suggest the authors do an effort to slightly reduce the length of section 2.1 in order to further improve the readability of the manuscript.

Answer: As suggested by the referee this Section is now substantially reduced and reads as follows: As mentioned in the introduction, we apply a CA model to a large and well documented wildfire that occurred in July 2012 in the Tavira and São Brás



de Alportel municipalities, located in Algarve, Portugal (Figure 1). The fire was first reported on July 18 (at about 13h UTC) and was considered as contained on July 21 (at about 17h UTC). The fire burned approximately 24,800 ha, mainly shrublands which made up about 64% of the affected area, and spread in heterogeneous, undulated terrain. It was the largest wildfire in Portugal in 2012, contributing to more than 22% of the total amount of 110,232 ha of burned area (ICNF, 2012) in that year. Since 2012 was a year of extreme drought, the meteorological background conditions were very prone to the occurrence of large fire events (Trigo et al., 2013). The fire propagated in two distinct phases. In the first stage, from 13:00 UTC on July 18 to 17:00 UTC on July 19, the fire burned about 5;000 ha, representing one fifth of the total burned area. In this phase, the wind direction was highly variable and the fire advanced through rugged terrain, with frequent shifts in the direction of maximum spread until it reached the Leiteijo stream. In the second stage from 17:00 UTC to 24:00 UTC on July 19 the fire turned into a major conflagration, greatly increasing its propagation speed and burning about 20,000 ha in 7 hours. When the fire reached the Odeleite stream it became orographically channeled, as an increase in wind speed led to fast and intense fire growth towards south, where heavy fuel loads were present. The fire split into two advanced sections heading west and east to the São Brás de Alportel and the Tavira municipalities, with a 10 km wide fire front. In addition, spotting created new fires up to two kilometers ahead of the fire front. All these factors allowed rapid propagation of the fire front while turning suppression extremely difficult.

2. The latter results from the ensemble of 100 models run. It would be of extreme interest to map model uncertainty; without any information about it, it would be very difficult to use the proposed model as a decision-making support tool.

Answer: The reviewer points out a relevant issue. However, we consider that mapping model uncertainty would be beyond the scope of a feasibility study such as the one we are describing. However, the issue of uncertainty is now discussed at the end of the new Section "5. Summary and conclusion", where the following sentences are added: Finally, it may be noted that results from the CA models are presented in terms of probability of burning as an outcome of ensembles of runs. This raises the issue of providing information of model uncertainty that is especially relevant if the CA model is to be used as a decision-making support tool. As discussed in Fischhoff and Davis (2014), characterizing model uncertainty involves identifying key outcomes, characterizing variability as well as internal and external validity, and finally summarizing uncertainty. Presentation of the impacts on fraction of burned area, bias and root mean square deviations when choosing different thresholds of probability of burning are a first step towards conveying results of uncertainty. Further steps in this direction will have to involve direct contacts with decision-makers when analyzing other large fire events namely the above-mentioned ones that took place in Portugal in June and October 2017.

3. Moreover, it would be interesting to have a sensitivity analysis concerning the variation of certain a priori fixed parameters, as the c1, c2 and as a coefficient of the model (which are now settled based on the values proposed by Alexandridis)

Answer: A sensitivity analysis to parameters c1 and c2 is now included in the manuscript (Figure 1) in the new subsection “2.5 Simulations” (of the new section “2 Data and methods”). The following sentences and figures were added to the manuscript: A sensitivity study was also performed to assess the effects of constants c1 and c2 on the propagation of fire (Equation 2). As shown in Figure 6, simulated values of total burned area and of burned area inside the perimeter of the fire scar increase (decrease) with increasing c1 (increasing c2). Moreover, above (below) a certain threshold of c1 (c2), a progressive departure is observed between the simulated values of total burned area and of burned area inside the perimeter of the fire scar, an indication that the simulated fire is spreading out of the recorded limits. Choice of c1 = 0.045 and c2 = 0.131 (Alexandridis et al., 2008) represents a compromise between burning a large fraction of the area inside the perimeter and spreading a small fraction outside.



Figure 6: Simulated values of the total burned area (red curves) and of the burned area inside the perimeter of the fire scar (blue curves) in units of the total area inside the perimeter as a function of c1 for fixed c2 = 0.131 (left panel) and as a function of c2 for a fixed c1 = 0.045 (right panel).

4. Similarly, it could be interesting to further explore the sensitivity of the result to the choice of the 0.2 probability threshold applied in section 4.2.

Answer: A sensitivity analysis to the choice of probability thresholds is now included in the manuscript (Figure 2) in new subsection “3.1 Constrained runs” (of new section “3 Results”). The following sentences and figures were added to the manuscript: Burned area in each one of the two ensembles was identified by assuming that a given pixel is a burned one when the modeled probability that it burned is larger than a fixed threshold. Each pixel identified as burned was assigned the respective time step as an indicator of the modeled time of burning. Time deviations were then computed by subtracting the times of burning as derived from the hotspots identified by MODIS (Figure 3, bottom panel). Finally, three measures of quality of the simulations were derived for different thresholds of probability, namely the fraction of burned area (relative to the total area inside the perimeter of the fire scar), the bias (simulated time minus time derived from hotspots) and root mean squared differences (between simulated time and time derived from hotspots). Figure 8 presents results obtained when using the model with the baseline wind rule (dashed lines) and the modified model (solid lines). In both cases, and as to be expected, the fraction of burned area decreases with increasing values of the threshold (Figure 8, top panel), the baseline model always presenting, for each threshold, lower values of burned area than the modified model. The baseline (modified) model presents positive (negative) values of bias for each threshold (Figure 8, middle panel) meaning that, on average, the simulations are late (in advance) when compared with times derived from satellite. In both cases, the bias increases with increasing values of threshold, the baseline model becoming more and more biased and the modified model approaching zero bias, although the rate of increase is smaller than the one of the baseline model. Finally, the root mean square difference (Figure 8, bottom panel) shows an opposite behaviour in the two cases, with values increasing (decreasing) with the threshold in the case of the baseline (modified) model. When considering all together the three measures of quality of the simulations, the modified is better performant than the baseline model and choosing values of threshold between 0.4 and 0.6 represents a good compromise in terms of simulated burned area and simulated time of fire propagation.

Figure 8: Fraction of the burned area inside the perimeter relative to the total area inside the perimeter of the fire scar (top panel), bias (middle panel) and root mean square difference (bottom panel) as a function of the probability threshold for c1 = 0.045 and c2 = 0.131. The dashed lines correspond to the baseline model and the solid lines to the modified model.

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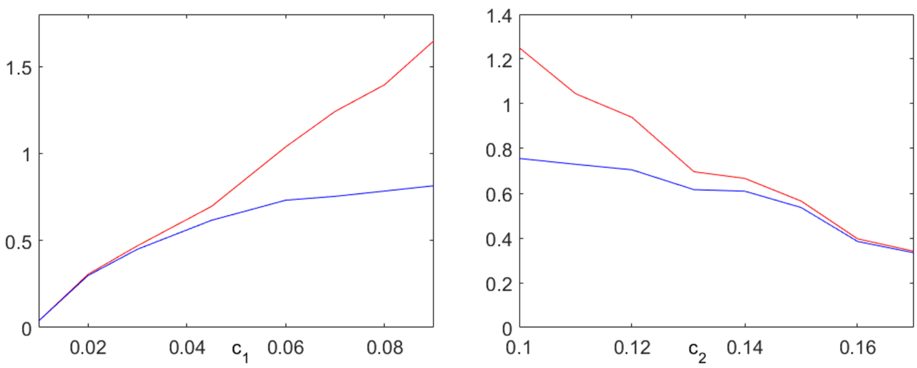


**Fig. 1.** Figure 6

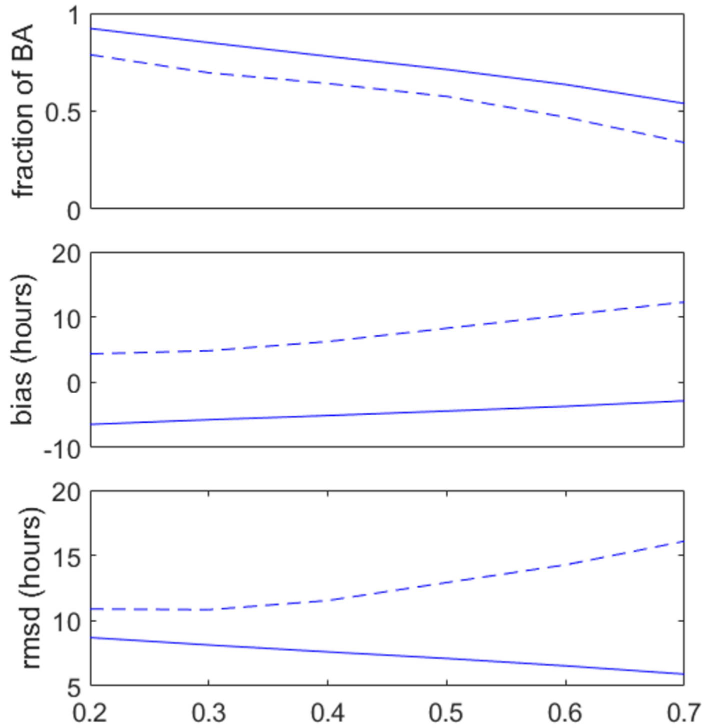


**Fig. 2.** Figure 8