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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 Reviewer #2 for his positive comments that greatly contributed to improving the manuscript.

General comments

1. Section 2 is essentially methods, so I suggest moving it to the methods section.

Answer: Section 2 is now part of the new "Section 2. Data and methods".

2. Sections 4.2 and 4.3 are a mix of results and discussion. Reorganizing it and renaming it "Discussion" would be an improvement and it could be the place to discuss

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the shortcomings indicated below.

Answer: Sections 4.2 and 4.3 were reorganized as suggested and the manuscript now contains a new “Section 3. Results” and a new “Section 4. Discussion”.

3. The ms. suffers from lack of explanation/rational for a number of decisions made regarding modeling, which seem too arbitrary. There is some confusion regarding the concept of probability, which in this ms. is (at least in part) akin to fire spread rate. Also, better discussion is needed of the strengths and weaknesses of the approach, especially given that I was not impressed with its performance and the tuning procedures seem to apply only to this fire in particular.

Answer: We agree with the reviewer about the misleading use of the term “probability factor”, namely in sections 2.2 and 3.1 of the original manuscript. We used the term “probability factor” to be consistent with Alexandridis et al. (2008) who used the term “probability”. Since “probability factors” do not in fact represent probabilities, we have replaced the term “probability factors” by “loadings”.

4. The Conclusion is too long. I suggest to rename it “Summary and Conclusion”.

Answer: The new Section 5 was renamed as suggested.

5. Title: Replace “fire prevention and fighting” by “fire management, more encompassing and elegant.

Answer: The title was changed as suggested.

Specific comments

6. P2, L17-20. This sentence is far from accurate. Current fire spread models and tools used operationally are deterministic but are empirical in nature, e.g. FARSITE. Thus the usage of deterministic models that “attempt a physics-based description of fires, fuel and atmosphere as multiphase continua prescribing mass, momentum and energy conservation, which typically leads to systems of coupled partial differential equations”

is restricted to the realm of research, as they are impossible to use in real time and their outputs are erratic. In fact, the physical mechanisms of fire spread remain largely unknown.

Answer: We agree with the reviewer and the text now reads as follows: Wildfire propagation is described in a variety of ways, be it the type of modelling (deterministic, stochastic), type of mathematical formulation (continuum, grid-based) or type of propagation (nearest-neighbor, Huygens wavelets), and often the formulation adopted combines different approaches (Sullivan, 2009; Alexandridis et al., 2011). For instance, the classic model of Rothermel (1972, 1983) combines fire spread modeling with empirical observations, and simplified descriptions such as FARSITE (Finney, 2004) neglect the interaction with the atmosphere and the fire front is propagated using wavelet techniques. Cellular Automata (CA) are one of the most important stochastic models (Sullivan, 2009); space is discretized into cells, and physical quantities take on a finite set of values at each cell. Cells evolve in discrete time according to a set of transition rules, and the states of the neighboring cells.

7. P2, L24. Again, empirical models are deterministic. “fill a gap” suggests they are somewhat half-way between empirical and physics-based models, which is not true. They are simply of a different kind.

Answer: We agree with the reviewer and the sentence “fill a gap between deterministic and empirical models” was removed. The entire paragraph now reads as follows: CA models for wildfire simulation prescribe local, microscopic interactions typically defined on a square (Clarke et al., 1994) or hexagonal (Trunfio, 2004) grid. The complex macroscopic fire spread dynamics is simulated as a stochastic process, where the propagation of the fire front to neighboring cells is modeled via a probabilistic approach. CA models directly incorporate spatial heterogeneity in topography, fuel characteristics and meteorological conditions, and they can easily accommodate any empirical or theoretical fire propagation mechanism, even complex ones (Collin et al., 2011). CA models can also be coupled with existing forest fire models to ensure better time accuracy of forest fire spread (Rui et al., 2018). More elaborated CA models that overcome typical constraints imposed by the lattice (Trunfio et al., 2011; Ghisu et al., 2015) perform comparably to deterministic models such as FARSITE, however at a higher computational cost.

8. P3, L3. I would better describe terrain as “undulated” rather than “steep”.

Answer: The text was changed accordingly.

9. P3, L11. Better use “fire proneness” instead of “wildfire propensity”.

Answer: As suggested by Referee #1, section 2.1 was substantially reduced (see answer to comment #1 by Referee #1). This sentence was accordingly removed from the manuscript.

10. P3, L12. This statement is too strong. Antecedent years rainfall influences subsequent fire activity in fuel-limited systems, which is not really the case of Portugal.

Answer: We agree with the reviewer. The sentence was removed from the manuscript (see also answer to comment #9).

11. P4, L1. “Consequently” indicates that the previous information leads to this conclusion. However, fire danger as per the FWI is determined by a combination of atmospheric influences and fuel dryness, being independent of fuel accumulation. The previous sentence refers drought and the typical weather conditions in the area, but not the prevailing weather during or before the fire, namely the dominant effect of wind speed. Revise (also, “consequently” should not initiate a paragraph).

Answer: We agree with the reviewer. The sentence was removed from the manuscript (see also answer to comment #9).

12. P4, L10. “protection”, not “salvation”.

Answer: The sentence was removed from the manuscript (see also answer to comment #9).

13. P4, L14. Replace “copious : : : loading” by “heavy fuel loads”.

Answer: The text was changed accordingly.

14. P4, L34. “shrubland”, not “shrubs”. Also, better use farmland or agriculture than cultivated, as the latter is ambiguous (it can denote planted forests).

Answer: “Shrubs” and “cultivated” were replaced by “shrubland” and “agriculture”, respectively.

15. P5, Table 1 and subsequent: you need to state what “probability” refers to. Fire spread?

Answer: The term “probability factors” was replaced by “loadings” (see also answer to comment #3).

16. P7, L10. From what follows, probabilities p express relative rate of spread rather than the probability of fire spread, e.g. according to a rule commonly used, rate of spread of the headfire perimeter is one order of magnitude faster than the backfire rate of spread, but their likelihood of spread is the same. Please make this more explicit.

Answer: In fact, as shown in Eq. 2, this effect is taken into account by the wind loading (pw), that makes the probability of backpropagation one magnitude lower than the frontal propagation. For instance, making c1=0.045, c2=0.131, and V=10m/s, we have loading pw equal to 1.5683 for theta=0° and equal to 0.1142 for theta=180°.

17. P7, L22. This in fact is the effect of slope, not the effect of elevation.

Answer: “Elevation” was replaced by “slope”.

18. P8, L8. You need to explain the rational for this rule and where does it come from. Physically it does not make sense, unless the increase in flame size due to wind would extend to new cells, which is impossible to happen.

Answer: This new rule intends to incorporate the effects due to fire spotting that were reported during the second stage of the Tavira event, when the wind speed was stronger. This is now explicitly mentioned in the manuscript: In order to better mirror the role played by the wind in fire propagation, a modification was introduced in the model by means of a new rule that allows propagation to non-adjacent cells with the aim of incorporating the effects due to fire spotting.

19. P8, L15. The first two paragraphs in Results, and part of the 3rd, belong in Methods.

Answer: The two paragraphs are now part of the new subsection 2.5 Simulations" (in new section 2. Data and methods").

20. P8, L16-19. If I understood correctly, this parameterization and the obtained time step depends on this wildfire rate of spread, right? Consequently, it cannot be applied to fires with different rate of spread.

Answer: Yes, the reviewer is correct, but this paper is a feasibility study. As mentioned in the manuscript, currently, we are applying the same model to other fire events, namely the events in Portugal on 15 October 2017 (where wind played a crucial role). Results obtained so far indicate good performance when these fire events are simulated with the proposed model and time steps.

21. P9, L2. Also, it depends of the changes in fuel types, or is this already accounted for in more effective fire fighting? (use fighting or suppression, not combat - replace here.

Answer: Yes, the reviewer is correct, and the sentence (in new subsection "2.5 Simulations") now reads: It may be noted that this setting along the scar boundary is not an artificial device since it reflects the known a posteriori fact that the shape of the scar resulted from effective fire-fighting in locations where changes in fuel types and the presence of roads make fire propagation harder.

22. P9, L15. Why 0.2? A threshold of p=0.5 is usually assumed for go/no-go events.

Again, this initial paragraph belongs to Methods.

Answer: We agree with the reviewer's point of view and results are now presented for threshold p=0.5.

23. P11, L6. Methods.

Answer: The text was moved to the new subsection 2.5 Simulations" (in new section 2. Data and methods").

24. P12. "Since fire containment was mainly due to actions by firemen along the perimeter". You don't know if this was the case (also in Fig. 9 legend): : : in may instances it should be due to changes in fuel type, topographic effects, or the presence of linear interruptions such as roads.

Answer: The phrasing is in fact misleading. We just wanted to point out that results of the unconstrained simulations indicate that the probability of burning is lower beyond the actual perimeter of the fire scar (as a result of changes in fuel type, topographic effects and the presence of linear interruptions such as roads). Since (successful) actions by firemen took place mostly along the perimeter of the fire scar, unconstrained simulations are a useful tool to assist decision makers during a fire event, by providing indications about locations of low burning probability to allocate resources for fire-fighting. Incidentally, information about fire combat were obtained from the fire report and from Rui Almeida (personal communication), who works at the National Forest Institute (ICNF) and took part in the fire fighting. The point raised by the reviewer is now explicitly mentioned in the new subsection "3.2 Unconstrained runs": Unconstrained simulations therefore indicate that the probability of burning is lower beyond the actual perimeter of the fire scar as a result of changes in fuel type, topographic effects and the presence of linear interruptions such as roads.

25. P13, L22. Still, 35% implies a high degree of underestimation in fire growth.

Answer: We are referring to 35% out of 55% of the area that burned during the explosive stage. It is true that there is still an underestimation, but this result is to be compared with the value of 10% that is obtained when using the baseline wind rule. The text was slightly changed to better reflect the above-mentioned point.

26. P13, L25. I don't see how this connection can be made, because probability of burning in this model is independent of fire suppression operations, and I don't think you know how fire suppression operations were carried out and where the resources were placed.

Answer: Results obtained show a marked decrease of probability of burning outside the observed fire scar, suggesting that this type of model may help decision-makers about the placement of the allocate fire-fighting forces during a fire event.

27. P13, L26. Why is this rule non-local? It suggests it is somewhat universal but no rational or basis was given for the rule.

Answer: "Non-local" was used in the sense that fire was allowed to propagate to non-adjacent cells. The sentence now reads: The proposed CA model with a wind rule that allows fire propagation to non-adjacent cells represents an improvement to the baseline model and reveals potential to be an added value in fire management.

28. P13, L27. I don't think there's evidence for this "very good" performance. Also, the added value for fire management is not proven. Why is this model preferable to fire growth simulators that are becoming more and more used operationally? Indicate advantages and disadvantages (preferably not here but previously in the Discussion).

Answer: The following sentences were added at the end of the new "Section 4 Discussion": The flexibility to the introduction of changes in properties of individual cells (e.g. when imposing constraints to fire propagation along the perimeter of the fire scar) as well as of transition rules (e.g. the proposed one on the effects of wind), together with the required low computational cost (that allows performing a very large number of runs in a short amount of time) make CA adequate tools to be used, either when planning

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controlled fires or when making decisions about fighting in an operational scenario. For instance, we are currently developing a mobile application (app) that allows the user to run the proposed modified model over the study area and modify the properties of the individual cells.

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