Authors' Reply

Manuscript: NHESS–2013–375
Title: Modelling wildland fire propagation by tracking random fronts
Submitted to: Nat. Hazards Earth Syst. Sci.

We would like to thank the Referee very much for the good evaluation of the manuscript that motivates us to continue the research and for the remarks, useful to clarify the presentation, and the very detailed report, useful to improve the quality of the text. Moreover, we thank the Referee for advices that fill our knowledge lacks on the phenomenology of wildland fires and give more scientific substance to the research.

Below, we reply item by item.

My specific comments, etc to the authors are as follows: The results are numerical, and since the approach cannot be evaluated against actual field measurements, I want the authors to describe the study as a 'proof–of–concept' or 'demonstration–of–concept.' The treatment of firebrands, for example, is a good example of proof–of–concept, where the idea of randomness is introduced without any physical qualification, and therefore not likely to be applicable to a real world scenario. But I do believe that, even without validation or evaluation against actual data, the approach has the potential to provide a more realistic treatment of wildfire propagation than the deterministic level-set based on ROS formulae or the classical reaction-diffusion formulation.

Reply: The Referee is right. In the revised version we have presented this research as a proof-of-concept (please, see abstract, section 4, section 5). In particular, at the end of the abstract the following sentence has been included:

"The presented study consitutes a proof-of-concept and it needs to be subjected to a future validation."

Style, typos, and grammar and further comments:

Overall: have the authors replace the word "noises" with "randomly-generated noise (hereafter referred to simply as noise)" throughout the article. The use of the word noises is not correct English.

Reply: The text has been checked and improved following Referee's correction.

Page 6522

lines 5 to 7: English is my native language, but in my science (atmospheric) the word 'support' is not used in this context. Please, either explain what the word support means in this context or replace it with another word that is more widely known? (I know the authors want to say that each numerical approach provides a single [deterministic] solution at every time step, when in fact wildfire propagation is highly turbulent and therefore random.)

The term 'support' is used again on *page 6524* **line 2**, and *page 6526*, **line 12**.

Reply: The term *support* comes from mathematical nomenclature and a standard definition is:

"In mathematics, the support of a function is the set of points where the function is not zero-valued".

However, we agree that it can be misleading if it is used in a paper intended for a multidisciplinary audience. The text has been checked and we use expressions similar to

"not zero on a infinite/compact domain".

line 10 (6): typo: consequently – **DONE**

line 12: typo: contour – **DONE**

line 25: typo: ... because it is motivated ... – **DONE**

Page 6523

line 2: typo: ... because it can cause disruption and is an important ... – **DONE**

line 10: ;see for example [add a semi colon] – **DONE**

line 15: change to: ... equations are just as good or even better for modeling diffusive ... – **DONE**

line 19: change to: This type of equation can embody ... – **DONE**

line 21: change to: In general the level-set method is particularly useful for handling ... – **DONE**

line 27: typo: alternatives ... – **DONE**

Page 6524

line 3: change to: complementary and can be reconciled. – **DONE**

line 6: change to: that can consequently affect fire-atmosphere interactions ... – **DONE**

line 11: Please add another reference for spotting in turbulent flow: – **DONE**

> Bhutia, S., M. A. Jenkins, and R. Sun, 2010: Comparison of fire-brand propagation prediction by a plume model and a coupled fire/atmosphere large-eddy simulator. J. of Advances in Modeling Earth Systems. Vol. 2, Art. #4, 15 pp., doi:10.3894/JAMES.2010.2.4.

line 12: typo: therefore – **DONE**

line 14: start a new paragraph with the 'Here, the ...' – **DONE**

lines 16–18: two noises ... change this to something more like: whose propagation is determined by the rate-of-spread (ROS) and noise-generated random turbulent transport and fire spotting. – **DONE**

line 23: typo: ... turns out to be deterministic ... – **DONE**

line 26: typo: fires – **DONE**

line: 29: change 'which' to 'that' – **This part of the Introduction has been re-arranged**

Page 6225

lines 4–5: change 'briefly reminded' to 'discussed briefly' – **DONE**

Page 6526

line 5: remove the word validated. [Mandel et al 2008 did not validate their model; they EVALUATED their model.] – **DONE**

Page 6527

lines 9–10: change to 'that represent, respectively, the burn area and the fire perimeter)' – **DONE**

Page 6528

line 14: change to 'and it has been implemented ...' – **DONE**

Page 6529

line 12: change to: The above argument is based on the idea that the active ... – **DONE**

Page 6531

line 6: change to: 'Hence, denoting the ensemble average by $\langle . \rangle$ ...' – **DONE**

line 20: change to: 'is classified ...' – **DONE**

Page 6532

line6: change to: 'it is recovered as' – **DONE**

line 9: define the 'kernel function' here.

Reply: The following definition has been inserted:

"the kernel function, i.e. the function that weights each contribution according to the distance from the point of interest, ..."

Page 6533

line 2: change to: 'Since the fireline velocity given by the ROS ...'

[I remove the word 'intensity' because I do not yet understand what the authors mean by intensity in this context. Later on page 6540 the maximum ROS is determined by the fireline intensity using Byram's formula, but until the reader gets to this point in the paper, then I suggest the authors remove the word 'intensity' applied to ROS.]

Reply: The Referee is right. We have mis-used the word *intensity*. Actually we refer to the modulus of the vector, then it is more correct the word *magnitude*. This has been checked and correct all over the text.

Page 6534

lines 13–14: Wording is awkward here. Please change it.

Reply: The wording now is:

"Hence, if for simplicity the proportionality in Eq. (19) is replaced by the equality, in points $\vec{x} \in \Omega'(t)$ such that $\psi(\vec{x}, t) = 1$ the ignition occurs and fire goes on according to (12) by setting $\mathcal{I}_{\Omega'}(\vec{x}, t) = 1$."

lines 4-5: Idisagree that ignition decay associated with pyrolysis gases is much greater than that of burning embers. Look for example at the online YouTube video, 'Inside the Fire' on http://www.youtube.com/watch?v=zvPa_yEEd4E.

Contact ignition by burning gases is instantaneous as far as a numerical time step is concerned. And if course not all fire brands are viable once they land (i.e., capable of lighting fuel ahead of the fire), although this means even greater 'randomness' and less probability of actual ignition by brands. So, some discussion on the realism of the two different assumptions of ignition delay as part of this description–of–concept, chosen to simply simplify the exercise (or as said on page 6536, lines 9 to 10, 'intended to investigate the potentiality of the proposed approach').

Reply: We thank the Referee to have highlighted us a question that has been very interesting both for the visual learning from the YouTube video and for suggesting a further random process to be included in the proposed approach.
This sentence has been removed from here and inserted in section 5.1 where Table 1 is introduced.
In particular, now it is:

"Moreover, in the following simulations, the potentiality of the proposed approach has been studied for simplicity with the assumption that the ignition delay associated to firebrands is much smaller than that associated to hot air, hence $\tau_{\mathrm{h}} \gg \tau_{\mathrm{f}}$ and it holds $\tau \simeq \tau_{\mathrm{f}}$."

This assumption is mentioned also in section 6 "Conclusions":

"Moreover, since ignition delay for fire spotting is stated to be shortest than for heating, a further increasing of propagation speed is generated in the direction of embers' landing that is assumed to be downwind."

line 12: Equation (19) has the problem that T_a is so much less than the actual fuel ignition temperature in a numerical model (say an LES). Can the authors discuss this, and is the model saved by setting the two functions equal to unity?

Reply: The fact that $T_a \ll T_{ign}$ is included as follows:

"Since it holds $T_a \ll T_{ign}$, formula (19) reduces to

$$\psi(\vec{x}, t) \propto \frac{T(\vec{x}, t)}{T_{ign}} . \qquad (20)"$$

Moreover, we have written in Eq. (21) the initial condtion $T(\vec{x}, 0) = T_a(\vec{x})$.

To conclude this item, it is not clear what the Referee means requiring to set the two functions equal to unity. The ignition temperature, that is supposed to be a fixed number, can be used as a scale and then its ratio with itself turns out to be 1. But if both are set equal to 1 it means that they are equal and then everything is burned. Actually this is what Eq. (21) says, i.e. the variation in time of temperature is null.

Page 6535

line 6: change 'noises corresponding to ...' to 'are the positions corresponding to randomly–generated turbulence and fire spotting.' – **DONE But we have used** *contributions* **in place of** *positions***.**

lines 20–21: Is it true that fire spotting is an intrinsically downwind-phenomenon? I don't think so. I think that it depends on the turbulence in the flow. If the turbulence in the flow produces a flow different and not downwind from the mean flow, then fire spotting will not be downwind. Furthermore, spotting cannot be an intrinsically a downwind-phenomenon and at the same time be treated as completely random. These are two ideas are physically incompatible.

Reply: We thank a lot the Referee to have highlighted this aspect. In the revised version this fact as been corrected and we have inserted in section 4 "Model discussion" the following sentence:

"To simplify the study of the present proof-of-concept, fire spotting is assumed to be independent of turbulence and to be a downwind-phenomenon even if these assumptions may not hold true in all cases and then not be entirely realistic."

and in section 6 "Conclusions":

"Moreover, since ignition delay for fire spotting is stated to be shortest than for heating, a further increasing of propagation speed is generated in the direction of embers' landing that is assumed to be downwind."

Page 6536

Equation (23): Therefore I would not have made the assumption in Equation (23). The authors should say that this assumption may not hold true in all cases, and that the assumption is chosen to simplify the exercise, even though it may not be entirely realistic.

Reply: As reported above, we have inserted in section 4 "Model discussion":

"To simplify the study of the present proof-of-concept, fire spotting is assumed to be independent of turbulence and to be a downwind-phenomenon even if these assumptions may not hold true in all cases and then not be entirely realistic."

Equation (24): And here, I would put some limits on where the embers impact the propagation of the fireline. If, based on this Gaussian model, the embers happen to fall "forward" (i.e., outside the fire perimeter), then they have a chance of igniting the fuel.

Reply: We thank again the Referee to have highlighted us this important aspect of the phenomenology of fire spotting.
We will take into account this for future developments.
The fact that fire spotting is assumed to be independent of turbulence is stated in the sentence inserted in section 4 "Model discussion" and typed also above in this letter:

"To simplify the study of the present proof-of-concept, fire spotting is assumed to be independent of turbulence and to be a downwind-phenomenon even if these assumptions may not hold true in all cases and then not be entirely realistic."

line 9: change to 'because intended to investigate the potentiality of the proposed approach' [i.e., remove the word mainly]. – **DONE**

line 17: change to 'but only the firebrands ...' – **DONE**

Page 6537

line 13: change to 'If a balanced Gaussian distribution is assumed and if only turbulence is ...' – **DONE**

Page 6538

line 23. Remove 'In opposition' – **DONE**

Page 6539

line 9: Remove 'quantitatively' ... because a numerical simulation based on a proof-of-concept modeling exercise cannot be call 'quantitative' in the strict definition of the word. – **DONE**

lines 12–13: change to The present code, still under active development and to be described thoroughly elsewhere in the future, aims ... – **DONE**

line 15: change to 'and coupled atmosphere-fire flow fields ...' – **DONE**

lines 17–20: change to "Since the aim of the present paper is a proof-of-concept to demonstrate the potential of the present approach, rather than simulating wildland fire behaviour under realistic conditions, ... oversimplified cases chosen to highlight the main features of the model." – **DONE**

Page 6540

line 1 and following: Remove 'Among the variety of wildland fire phenomenology that the numerical code permits to simulate' and change to 'A fireline propagating in a flat terrain covered by an idealized Pinus ponderosa ecosystem has been selected for simulation, following previous analyses Sardoy et al. (2007, 2008) and Perryman et al. (2013) on the same issues.' – **DONE**

lines 13 to 20: Better to remove all discussion of corrective factors for terrain slope. Slope correction is difficult. Just leave it. Simulation is on flat ground.

Reply: The part regarding the slope has been removed, but not that regarding the paramenter α. This parameter emerges to combine the Byram formula and fireLib and Fire Behaviour SDK libraries. Since we are following parameterization and studies previously performed by Sardoy et al. (2007, 2008) and Perryman et al. (2013), we have to used Byram formula that explicitly considers fire intensity.

Page 6541

line 3: the velocity ... is assumed to be equal to 10 m/s. [I.e., units for velocity must be correct.]

Reply: That unit is referred to the height of the tree canopy. Now the sentence reads:

"the wind velocity, U_t, is intended as the velocity measured at the top of the tree canopy that is assumed to be high 10 m as by Sardoy et al. (2008)."

lines 6–7: More correct to say 'In this simplified analysis, the turbulent diffusion coefficient D_T, and ignition delays of the hot air and of the firebrands are assumed constant throughout the numerical simulations.' – **DONE**

Page 6543

line 17: change to 'strong sensitivity to different ...' – **DONE**

line 22: remove the 'if' – **DONE**

lines 23–27: change English to ... 'These four cases, displayed in Figs. 1, 2, 3 and 4, show that the differences between cases are the consequences of the air pre-heating action due to the heat transfer mechanism enhanced by turbulence and of the rapid ignition connected to embers landing in the yet-to-burn region ahead of the fire line front.' – **DONE**

Page 6544

line 10: change to 'overcome' – **DONE**

lines 21–24: I am not sure I agree with the statement that in a long-term analysis, the simulation results presented in Figs. 1d, 2d, 3d and 4d would show that the fire is capable of overcoming the firebreaks solely due to heating mechanism connected to turbulence. I think this depends on the depth and kind of firebreak. I think that the authors should say that Pagnini and Massidda (2013) found this to be true, but that the phenomenon of turbulent gases overcoming firebreaks should be investigated further. – **DONE. The Referee is right. All that part has been cancelled.**

Page 6545

line 19: change to '... fire spotting phenomenon have ...' – **DONE**

Page 6546

lines 7-8: the authors write: 'The presence of fire spotting leads the fireline to be faster in the leeward sector than in the windward sector which is affected solely by turbulence.' I am not sure this sentence should be included. It is not surprising that fire spotting increases fire line propagation in the leeward sector when that leeward motion by firebrands is built into the formulation. – **DONE. This sentence has been cancelled.**

line 19: change 'fire faster propagation' to 'faster fire propagation' – **DONE**