Fire Technology, 55, 1919–1925, 2019

Manufactured in The United States
https://doi.org/10.1007/s10694-019-00856-2

Letter To The Editor

Comments on ''Evaluating Crown Fire Rate of Spread Predictions from Physics-Based Models''

M. G. Cruz, CSIRO, GPO Box 1700, Canberra, ACT 2601, Australia*
M. E. Alexander, Wild Rose Fire Behaviour, 180 - 50434 Range Road 232, Leduc County, AB T4X 0L1, Canada

Dear Editor,

In a paper published in the January 2016 issue of *Fire Technology*, Hoffman et al. [1] provide an assessment of crown fire rate of spread predictions of two physics-based models, FIRETEC [2] and the Wildland-urban interface Fire Dynamics Simulator (WFDS) [3, 4], through an indirect comparison with a large data set of wildfire observations ($n = 57$) published by us [5], which they refer to as AC06. The AC06 data set was compiled from various published sources for the purpose of evaluating the performance of an empirical model we developed for predicting active crown fire rate of spread [6].

We commend the authors for their effort to evaluate the outputs from such complex model systems against real-world data. However, we disagree with certain statements made by Hoffman et al. [1] regarding: (1) their view of the presumed limitations of our data set derived from case study information of Canadian and U.S. wildfires and (2) a number of conclusions they have reached in their evaluation of FIRETEC and WFDS for the prediction of crown fire rate of spread.

1. Misinterpretations of the Wildfire Case Study Data Set

We found that Hoffman et al. [1], misinterpreted the assumptions we used in developing the [5] wildfire data set regarding the main drivers of crown fire propagation (i.e. wind speed, fine dead fuel moisture content, canopy fuel characteristics). In this respect, it is important to clarify for the journal's readership the value of these assumptions and thus of the data set as a whole:

1. Contrary to the claim of Hoffman et al. [1, p. 226], no mention is made in AC06 that the fires in our data set ''were categorised as either active or passive

* Correspondence should be addressed to: M. G. Cruz, E-mail: miguel.cruz@csiro.au

crown fires''. To our knowledge (and for the purpose of the data set), all of the wildfires contained in [5] involved active crown fire type behaviour [7].

2. Hoffman et al. [1, p. 226] states that ''several calculations were performed to modify the data set to meet their purpose'', leading to the possible interpretation that altered values were used in the compilation of the AC06 data set, and a misinterpretation of the value of the data. Indeed, no data was modified and the only reason ''calculations were performed'' was to standardise the data to meet the model requirements of [6]. For example, the wind speeds for all the U.S. wildfires in the AC06 data set were reported at a 6.1-m height in the open [8] and had to be adjusted to the international standard 10-m open height [9, 10] used as a model input in [6]. The suggestion that this conversion would add significant uncertainty to model simulations does not consider that much higher uncertainty arises from extrapolating point wind speed data over a broad spatial and temporal environment.
3. Hoffman et al. [1, p. 230] claimed that the canopy bulk density (CBD) values we reported on in [5] ''were not based on actual on-site data and thus may not provide an accurate estimate of the actual canopy bulk densities''. In reality, as noted in [5], in compiling the AC06 data set we used actual sampled data when it was available for a given wildfire case study and otherwise relied upon information gleaned from CBD studies (e.g. [11]), that were based on tree measurements and biomass equations, for the same general geographical region, where possible, in which the wildfire occurred. This provided us with the best estimate of CBD over the broad spatial scale that characterised each wildfire run.
4. Hoffman et al. [1, p. 228] indicated that the estimated fine fuel moisture (EFFM) values given in the AC06 data set ''were estimated without knowledge of the actual conditions''. Contrary to their assertion, the EFFM values were determined from air temperature, relative humidity, time of year, and time of day documented for each wildfire as per the manual tabular procedure of [12] or as incorporated in the BehavePlus fire modelling software [13]. The EFFM tables (no equations exist) of [12] have proven to provide reliable results under wildfire conditions (e.g. [14]). Hoffman et al. [1, p. 227] also claimed we assumed ''that all fuels were shaded from solar radiation''. This is not correct, as the EFFM values were in fact calculated using the $> 51\%$ interval option of [12] for the degree of shading (based on cloud cover and canopy coverage). This option is based on the assumption that if there is enough canopy cover to sustain active crown fire propagation, the degree of shading should be higher than 51%. This assumption follows the approach taken by Rothermel [15] in the development of his semi-empirical crown fire rate of spread model.
5. Following the reasoning by Hoffman et al. [1] that the evaluation of fire spread models need measured fuel moisture content (and any other input variables for that matter) would mean that no model could be evaluated against wildfire data, as it would be logistically near impossible, and notably unsafe [16], to conduct spatially and temporally relevant dead and live fuel moisture sampling in a timely manner in the direct vicinity of a high-intensity free-burning wildfire.

The evaluation of fire spread models against wildfire data is part of the process of model development and necessary to their acceptance, by researchers and end-users alike [17]. This evaluation process will always require the use of assumptions to overcome unknowns in the data. A pragmatic approach is necessary to evaluate comprehensive models of complex phenomena such as wildfires. Despite the perceived criticisms by Hoffman et al. [1] to the value of the AC06 data set, the assumptions we used have been shown to be sound. They are what allowed its use to independently evaluate operationally-used crown fire rate of spread models [6, 15].

2. Data Analysis and Interpretation

Hoffman et al. [1] chose to undertake an indirect comparison between the data in AC06 and unrelated data from a number of simulation studies. The authors state that they chose not to make a direct evaluation of FIRETEC and WFDS against the wildfires contained in AC06 because of limited information in its data set. Instead they [1] chose to compare the performance of the physical models against a facile 'empirical' model which explained only 56% of the variation in the data. We believe the contribution of the Hoffman et al. [1] analysis to our understanding of the performance of FIRETEC and WFDS would have been enhanced had the authors conducted a direct model evaluation from which error statistics and trends could be calculated from the contrast between observed and predicted rates of fire spread as undertaken by [5, 6], for example. Such an approach would require a number of assumptions to be made, and although the end result would not be a full validation, it would have provided trends that could be used to identify areas of future model improvement. Both FIRETEC and WFDS have been assessed against data sets with the same level of detail as [6] by [3, 18–20].

It is our opinion that although the indirect analytic approach taken by Hoffman et al. [1] allows one to visualise some of the trends in the two physics-based models and their relation with the AC06 data set, the conclusions drawn from their results are unfounded. The positive comments of [1, p. 230] on model performance are based on the observation that "Overall, 86% of all simulated ROS values using FIRETEC and WFDS fell within the 95% prediction interval of the empirical data". This result is not surprising as the wide variability in the fire spread rate observations, as dictated by the range of fuel moisture and fuel complex structures, result in a wide prediction interval. As such, the high percentage of simulated values within the prediction interval do not reflect the predictive ability of these models against observed crown fire behaviour, but hence is a consequence of the notoriously wide intervals.

The main reasons we do not believe that a positive assessment can be justified are as follows:

1. As pointed out by Hoffman et al. [1, p. 228], the FIRETEC and WFDS simulations resulted in an over-estimation of crown fire spread rates. A closer inspection of the graphical results presented in Fig. 1 of their paper show the

models exhibit very high over-prediction bias for low wind speeds (e.g. < 15 km h^{-1}), a noticeable, but lower over-prediction for wind speeds between 20 km h^{-1} and 30 km h^{-1}, and a better fit to the data for wind speeds above 40 km h^{-1}.
2. Hoffman et al. [1, p. 228] used the percentage of data within the confidence interval as a measure of model adequacy [21]. Although this metric might make sense for ecological studies as a simple assessment for mathematical models, its application to wildland fire spread models is questionable due to the consequences of model prediction errors. As an example, this evaluation metric implies that a 200% prediction error (e.g. observed rate of spread of 20 m min^{-1} and predicted rate of spread of 60 m min^{-1}) is a good outcome. Such an error might seem reasonable for an ecological modelling study, as put forward by [21], but certainly not when applied to wildfire prediction, where human lives and the success of fire-fighting operations might depend on the accurate prediction of fire spread across the landscape [17].
3. The polynomial model developed by [1, p. 228] with an intercept value of 24.5 m min^{-1} resulted in abnormal results appearing acceptable. From a practical point of view, a fire on level ground will not be capable of crowning in a vertically stratified coniferous forest fuel type with a rate of spread of 24.5 m min^{-1} in absolute nil wind conditions. There are a number of other simulations in Fig. 1 of [1] that one could say are unlikely, if not impossible to occur in a wildfire setting, namely crown fire rates of spread of 40 m min^{-1} under a light breeze (wind speed < 10 km h^{-1}) on flat ground. For these conditions, the WFDS simulations reported in Fig. 1 of [1] imply that a crown fire can spread at 1/3 the speed of the wind. These results, despite being erroneous, are considered by Hoffman et al. [1] as appropriate as they are within the 95% prediction band.
4. Hoffman et al. [1] suggested that the over-prediction bias observed when comparing the simulated data set with the model fit based on the AC06 data set given in Fig. 1 of their paper might be related to the CBD used in their model simulations being higher than the values given in the AC06 data set. This reasoning misses the fact that the FIRETEC rate of spread simulations have an inverse relationship with CBD, as described in the sensitivity analysis conducted by [19]. The results given in [22] also show an increase in rate of fire spread with a decrease in CBD, although it is unclear if this increase is due to the effect of CBD alone, or the result of complex and confounding effects within the fire environment. These results suggest that the higher CBD values used in the FIRETEC simulations are in effect reducing the over-estimation trend, not contributing to it as suggested by Hoffman et al. [1].

3. Closing Remarks

Hoffman et al. [1, p. 225] point out the "limited amount of model assessment" of FIRETEC and WFDS is due to a "lack of field-scale experimentation or observation in which data collection is adequately complete" for these models. As pointed out by the two model evaluation references [21, 23] used by [1], model assessment is much more than just direct comparison between model outputs and observed data. Parametric studies, such as done by [19], comparison with other models [3, 24], and extreme-condition tests [20], are examples of model evaluation methods that will provide detailed information on model behaviour and adequacy without needing detailed field data.

A decade ago we extended an open offer [25] to work with others in the wildland fire research community on the application of our models for predicting the onset of crowning and crown fire rate of spread, and by extension, the use of the corresponding data sets in model development and performance evaluation. That same offer still stands.

Acknowledgements

The authors wish to thank Andrew Sullivan, Wesley Page and Kelsy Gibos for their reviews of this letter.

References

1. Hoffman CM, Ziegler J, Canfield J, Linn RR, Mell W, Sieg CH, Pimont F (2016) Evaluating crown fire rate of spread predictions from physics-based models. Fire Technol 52:221–237. https://doi.org/10.1007/s10694-015-0500-3
2. Linn RR, Reisner J, Colman JJ, Winterkamp J (2002) Studying wildfire behavior using FIRETEC. Int J Wildl Fire 11:233–246. https://doi.org/10.1071/WF02007
3. Mell W, Jenkins MA, Gould J, Cheney P (2007) A physics-based approach to modelling grassland fires. Int J Wildl Fire 16:1–22. https://doi.org/10.1071/WF06002
4. Mell W, Maranghides A, McDermott R, Manzello SL (2009) Numerical simulation and experiments of burning Douglas fir trees. Combust Flame 156:2023–2041. https://doi.org/10.1016/j.combustflame.2009.06.015
5. Alexander ME, Cruz MG (2006) Evaluating a model for predicting active crown fire rate of spread using wildfire observations. Can J For Res 36:3015–3028. https://doi.org/10.1139/x06-174
6. Cruz MG, Alexander ME, Wakimoto RH (2005) Development and testing of models for predicting crown fire rate of spread in conifer forest stands. Can J For Res 35:1626–1639. https://doi.org/10.1139/x05-085
7. Van Wagner CE (1977) Conditions for the start and spread of crown fire. Can J For Res 7:23–34. https://doi.org/10.1139/x77-004
8. Andrews PL (2012) Modeling wind adjustment factor and midflame wind speed for Rothermel's surface fire spread model. General Technical Report RMRS-GTR-266. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO. https://doi.org/10.2737/rmrs-gtr-266
9. Lawson BD, Armitage OB (2008) Weather guide for the Canadian Forest Fire Danger Rating System. Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, AB. http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/29152.pdf

10. Albini FA (1981) Spot fire distance from isolated sources—extensions of a predictive model Research Note INT-309. USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT. https://www.frames.gov/documents/behaveplus/publications/Albini_1981_INT-RN-309.pdf
11. Cruz MG, Alexander ME, Wakimoto RH (2003) Assessing canopy fuel stratum characteristics in crown fire prone fuel types in western North America. Int J Wildl Fire 12:39–50. https://doi.org/10.1071/WF02024
12. Rothermel RC (1983) How to predict the spread and intensity of forest and range fires. General Technical Report INT-143. USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT. https://doi.org/10.2737/int-gtr-143
13. Andrews PL, Bevins CD, Seli RC (2003) BehavePlus fire modeling system, version 2.0: user's guide. General Technical Report RMRS-GTR-106WWW. USDA Forest Service, Rocky Mountain Research Station, Ogden, UT. https://doi.org/10.2737/rmrs-gtr-106
14. Hartford RA, Rothermel RC (1991) Fuel moisture as measured and predicted during the 1988 fires in Yellowstone Park. Research Note INT-396. USDA Forest Service, Intermountain Research Station, Ogden, UT
15. Rothermel RC (1991) Predicting behavior and size of crown fires in the Northern Rocky Mountains. Research Paper INT-438. USDA Forest Service, Intermountain Research Station, Ogden, UT. https://doi.org/10.2737/int-rp-438
16. Rothermel RC, Rinehart GC (1983) Field procedures for verification and adjustment of fire behavior predictions. General Technical Report INT-142. USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden UT. https://doi.org/10.2737/int-gtr-142
17. Alexander ME, Cruz MG (2013) Are the applications of wildland fire behaviour models getting ahead of their evaluation again?. Env Model Softw 41:65–71. https://doi.org/10.1016/j.envsoft.2012.11.001
18. Linn R, Anderson K, Winterkamp J, Brooks A, Wotton M, Dupuy J-L, Pimont F, Edminster C (2012) Incorporating field wind data into FIRETEC simulations of the International Crown Fire Modeling Experiment (ICFME): preliminary lessons learned. Can J For Res 42:879–898. https://doi.org/10.1139/x2012-038
19. Marino E, Dupuy J-L, Pimont F, Guijarro M, Hernando C, Linn R (2012) Fuel bulk density and fuel moisture content effects on fire rate of spread: a comparison between FIRETEC model predictions and experimental results in shrub fuels. J Fire Sci 30:277–299. https://doi.org/10.1177/0734904111434286
20. Pimont F, Dupuy JL, Linn RR (2014) Fire effects on the physical environment in the WUI using FIRETEC. In: Viegas DX (ed) Advances in forest fire research. Coimbra University Press, Coimbra, Portugal. https://digitalis.uc.pt/en/livro/fire_effects_physical_environment_wui_using_firetec
21. Rykiel EJ (1996) Testing ecological models: the meaning of validation. Ecol Model 90:229–244. https://doi.org/10.1016/0304-3800(95)00152-2
22. Linn R, Winterkamp J, Colman JJ, Edminster C, Bailey JD (2005) Modeling interactions between fire and atmosphere in discrete element fuel beds. Int J Wildl Fire 14:37–48. https://doi.org/10.1071/WF04043
23. American Society for Testing and Materials (2005) Standard guide for evaluating the predictive capability of deterministic fire models. ASTM E 1355-05a, American Society for Testing Materials, West Conshohocken, PA. ftp://185.72.26.245/Astm/1/Section%2004/ASTM0407/PDF/E1355.pdf
24. Linn RR, Cunningham P (2005) Numerical simulations of grass fires using a coupled atmosphere–fire model: basic fire behavior and dependence on wind speed. J Geophys Res 110:D13107. https://doi.org/10.1029/2004JD005597

25. Alexander ME, Cruz MG (2009) Recent advances in modeling the onset of crowning and crown fire rate of spread. In: Masters RE, Galley KEM, Despain DG (eds). The'88 fires: Yellowstone and beyond. Tall Timbers Research Station Miscellaneous Publication No. 16, Tallahassee, FL. https://www.nps.gov/yell/learn/nature/upload/9thconf_88fires.pdf