RESPONSE TO REVIEWERS COMMENTS

"The Community Fire Behavior Model for coupled fire-atmosphere modeling: Implementation in the Unified Forecast System" by Pedro A. Jiménez y Muñoz, Maria Frediani, Masih Eghdami, Daniel Rosen, Michael Kavulich, and Timothy W. Juliano.

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Reviewer #1

Review of "The Community Fire Behavior Model for coupled fire-atmosphere modeling: Implementation in the Unified Forecast System" by Pedro A. Jiménez y Munñoz, Maria Frediani, Masih Eghdami, Daniel Rosen, Michael Kavulich, and Timothy W. Juliano.

The manuscript presents a fire behavior model that can be coupled with the existing atmospheric models. The study presents results when the community fire behavior model is coupled with the Unified Forecast System for fire spread episode focused during Summer of 2020 in Colorado. The model is run in a standalone model, coupled mode and the results are compared against the WRF-Fire model predictions.

Overall, the manuscript is well written and the fire behavior model is well explained. Figures and model schematic depictions are clear. The study is valuable as the CFBM model presented could be run with a user-selected atmospheric model as long as the required variables are present. The manuscript is suitable for publication after revisions addressing the below comments.

RESPONSE

We would like to thank this reviewer for the time she/he devoted to revise the manuscript and for the positive perspective about the manuscript. We have improved our explanations and revisited the experimental set up in order for UFS and WRF to have the same set of parameterizations, time step, and number of vertical layers. We have also increased the grid spacing from 3 km to 1 km. As a result, there is a better agreement with the winds from UFS and WRF and the simulated perimeters. We have also introduced quantifications of the agreement between the simulated perimeters. Below, we have reproduced the comments of this reviewer and we have provided a detailed answer indicating how we have modified the original version of the manuscript. We believe the modified version of the manuscript is a stronger contribution.

COMMENT 1

Comments:

1. Expand or describe the wind and slope correction terms mentioned in Equation 1. Without the wind correction term formula, I am having difficulty understanding why the user would have to select a fire wind height, when it is much simpler to use the 10-m winds (which are usually available from many atmospheric model outputs) as the driving force for the fire perimeter. Also, is there an upper limit for the rate of spread in the model to address any unrealistic values or sudden spikes such as the one observed for fire heat/vapor fluxes and emissions shown in Figure 9?

RESPONSE

These terms involve complicated parameterizations and adding them would be probably too much level of detail and thus we prefer to cite the relevant document with all the detailed explanations: "*A comprehensive description of each term involved in the parameterization is provided by Andrews (2018)*". The height selected by the user represents the mid-flame height. We have added this information to the new version of the manuscript. Imposing the height of the winds that drive the fire is the only option in WRF-Fire and that is why we used it given the main objective of testing the consistency of our implementation in UFS-CFBM. Other options involve the use of wind adjustment factors (WAF), or in other words, using a different height for each of the fuel types depending on the fuel characteristics. The use of WAFs in combination with the 10 m winds, as the reviewer suggested, is an attractive option for extensions of the CFBM and we are currently testing this option (Eghdami et al. 2025). We have clarified these aspects too: "*In the future, we would like to alleviate this subjective choice and implement the use of wind adjustment factors to automatically identify the height that drives the fire evolution based on the fuel characteristics (Eghdami et al. 2025).*". The upper limit of the rate of spread is 6 m/s and we now say this in the new version of the manuscript: "*The fire rate of spread is limited to a maximum of 6 m/s*". The spikes in the old Figure 9 were related to a different aspect of our previous experimental set up (the time step) that we have fixed in our new experimental set up (new Figure 10 in the manuscript).

COMMENT 2

2. Since the WRF model and the UFS model were initialized from HRRR, why is there such a bias in the wind speed predicted by UFS? Did the authors perform any sensitivity analysis to identify the source of this discrepancy? Can we expect UFS to underestimate the wind speed in general? Are there other studies in the literature that pointed this out? Choosing a different height simply to match the WRF wind speed may not fully address the complexities involved, especially when the height is user given. As the authors mentioned, the choice of fire wind height is one of the key input parameters in running the model. Further analysis could help the CFBM users to understand the uncertainties involved and make an educated choice of the fire wind height. If the intention is to simply use the WRF-Fire model as the ground truth or reference, use of different physics parameterizations in UFS compared to WRF would obviously yield different results. Also, as mentioned near Line 105; how will the model perform if (say) 10m winds are interpolated to 2.5m or 5m based on the logarithmic profile.

RESPONSE

In the new version of the manuscript we have resolved this discrepancy. It came for the use of different land surface models which affects the roughness length which strongly conditions the magnitude of near surface winds. The wind speed from WRF and UFS are in much better agreement now (new Figure 7). The correlation, bias, and mean absolute error between the wind speed from UFS and WRF is 0.69, -0.3 m/s, and 0.5 m/s, respectively. We have added this information to the manuscript. In the future we would like to avoid the user having to select the height using WAFs (see answer to previous comment). Using the 10 m winds in combination with the logarithmic profile is not going to change results much and that is why we would like to use the 10 m winds in the future. For now we use the option available in

WRF-Fire which allows for a clean comparison of the models to ensure the adequacy of our implementation.

The other option in WRF-Fire, which we did not test here but we describe, is to use the winds from higher vertical levels and the logarithmic interpolation to decouple the impacts of the fire in the atmosphere since the Rothermel parameterization of the rate of spread was developed for using ambient winds to drive the fire evolution.

COMMENT 3

3. It is very surprising that the model heat flux value differs outside the fire perimeter, especially in the UFS runs (Figure 10). Even more surprising is the presence of negative values in the UFS heat flux differences. If the only difference among the coupled and uncoupled simulations is the feedback from the fire pixels to the atmosphere, why will there be any changes to the surface heat flux far away from the fire perimeter! For the purpose of comparison, in Figure 10, it would be better if the WRF variable also includes the total surface heat flux, as the uncoupled values are subtracted from the coupled, only the fire induced heat flux would remain.

RESPONSE

Only UFS shows this behavior because there is only one heat flux that includes the standard head flux from the land surface model plus the fire contribution. The positive/negative values outside the fire perimeter result from subtracting the fluxes from the one-way simulation to the two-way simulation and nonlinear effects in the atmosphere introduced by the fire which affects the standard land surface model heat flux. This is not the case for WRF-Fire (the values are always positive) that has a dedicated variable for the fire heat flux (that is zero for an uncoupled simulation). Hence for WRF-Fire, only the fire induced heat flux is shown. This is the cleanest comparison we can provide. We have clarified this in the version of the manuscript.

COMMENT 4

4. Interesting to see the mean wind speed unaffected even if the temperature increased in both WRF and UFS models as a result of 2-way coupling, which would change the vertical velocity in the model. It would be better to show the change in vertical velocity due to 2-way coupling and it could be used to justify the insignificant effect of 2-way coupling on the fire spread and mean winds shown.

RESPONSE

We have calculated the impacts in the vertical velocity near the ground. See Figure 1 of this document. There are no noticeable impacts in the first few hours of the simulation, but when the fire grows, 12 h into the simulation, we see, as expected, an increase in the vertical velocity in both WRF and UFS. We have included this figure in the new version of the manuscript.

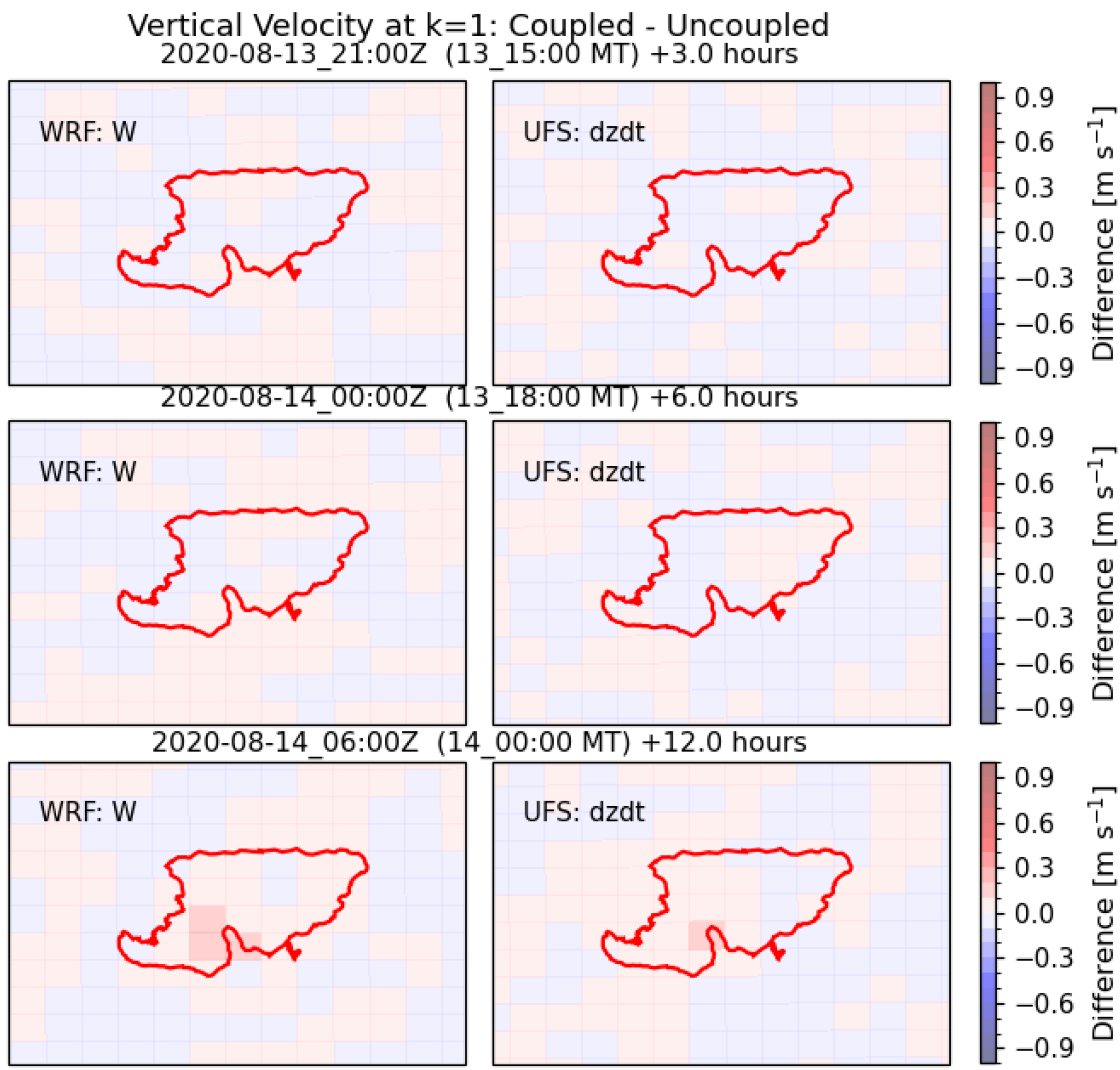

Figure 1: Fire heat flux differences between two-way and one-way simulations using the WRF model (left column) and the UFS model (right column) at 3 h (top row), 6 h (middle row), and 12 h (bottom row) into the simulations. To illustrate the location of the fire we also show Perimeter 3 valid for August 14 2216 UTC (red solid line).

COMMENT 5

5. It is hard to follow the discussion near Line 385, about the large fluctuations in fluxes and emissions in the UFS-2way run. Why would the WRF-Fire time step 18s be relevant to the fluctuations in UFS output? Also, I thought WRF used a fixed 12s timestep! Why do the large fluctuations in UFS-2way variables start 3 hours after the fire initialization?

RESPONSE

We have rerun the simulations in the new version of the manuscript using 1 km grid spacing and a time step of 4 s in all the simulations. The unclear explanations are no longer needed since now there is a much better agreement between the simulations. There are still peaks of smaller magnitude and these peaks do not need to perfectly align because UFS and WRF use different dynamical cores and the atmosphere is nonlinear which affects the winds and the fire evolution. However, we would expect to see good resemblances in the lower frequency evolution of the fire fluxes from both models, and that is what we see in the new version of the figure (correlation 0.77) with the time series of the fluxes (see new Fig. 10 and updated discussion).

COMMENT 6

6. Line 421: It's hard to justify this line: "In any case, there is no evidence of a systematic bias in the rate of spread for this case." From Figures 5 and 8, the fire area from UFS (1-way or 2-way) seems to be larger than the WRF simulated area. This is counterintuitive when one takes into account the mean wind speed differences. For a good portion of the simulated time, the mean wind in UFS is weaker than in the WRF and yet the fire area in UFS is larger than in WRF. Authors could add the timeseries of the difference between the fire area simulated by UFS and WRF for the -P1 and -P2 cases to justify if there is a systematic bias.

RESPONSE

This sentence referred to the results for the simulations starting from fire perimeters. We have rerun our simulations to have a better agreement between WRF and UFS configurations. We now have the same set of parameterizations, time step, and number of vertical layers. There is much better agreement now in the simulated perimeters for UFS and WRF for the -P1 an -P2 cases. We have updated our explanations and removed that sentence in Section 4.2.4.

Also in the new Figures 5 and 8, now Figures 7 and 9, there is good agreement between the UFS and WRF winds. The correlation, bias, and mean absolute error between the wind speed from UFS and WRF is 0.69, -0.3 m/s, and 0.5 m/s, respectively. Note that we are showing the wind averaged over the complete fire perimeter and there will be regions where the wind points towards the burned area and this wind speed does not contribute to advancing the fire perimeter. See the updated description of the figures.

COMMENT 7

7. For the 2way runs, please add details about which layer the smoke emissions area added and that the smoke is being added as a passive tracer, i.e., it does not carry any thermodynamic or chemical properties. Even better would be to show a 3D visualization of the fire progression with smoke tracer and stream lines showing any updrafts over the fire.

RESPONSE

We have clarified our explanations of the smoke tracer: "*The smoke emissions are added to the first atmospheric layer of a passive tracer to represent the smoke transport and dispersion associated with atmospheric dynamics.*"

COMMENT 8

8. Discuss any limitations of the CFBM. For example, can it be coupled with very high resolution models (grid size less than 100m or large-eddy scales)?

RESPONSE

Yes, the fire model can be run with the atmosphere configured in large-eddy simulation (LES) mode as it has been done before with WRF-Fire (e.g., Jimenez et al. 2018). Currently, the main limitation of CFBM with respect to other fire models is that the model can run in only one cpu. We are working on adding the parallelization. We already mentioned this in the manuscript but we now say it one more time: "*Currently, the main limitation is that CFBM can run with just one dynamical core but we are working to include OpenMP parallelization soon.*"

COMMENT 9

9. Line 294: Expand on or use a reference for the line "And third, we updated the VEGPARM.TBL to correct for a bug in the table." What bug?

RESPONSE

There were some missing or incorrect lines in the table. This is a fix from the official WRF release: https://github.com/wrf-model/WRF/commit/f0a4f0359aa28306ac2c59c559fed02db4ebf077

We now say "*And third, we updated the VEGPARM.TBL to correct for missing/incorrect lines, this fix being part of the official WRF release.*"

COMMENT 10

10. Use consistent references, in the discussion around Figure 5, at places the subplots were referred to as Figure 5a and later in the text, they were referred to as Figure 5 (right/left).

RESPONSE

Thanks, we have corrected this.

COMMENT 11

11. Describe the red perimeter line in Figure 10 in the caption. It would be better if Figures 10, 11 and 12 are shown for the same times as in Figures 4 and 7.

RESPONSE

We have added the description in the caption of Figure 10. We show results for the first hours of the fire evolution, 3 h, 6 h and 12 h into the simulation to minimize the impact of nonlinear effects of the atmospheric evolution. The second one, 6 h into the simulation, is the same time as the first panel in Figures 4 (new Fig. 5 in the new version of the manuscript) and 7 (new Fig. 8).

COMMENT 12

12. As this is similar to and compared with WRF-Fire in the manuscript, it would be useful for the end user to know about any benefits CFBM would have over other existing models such as WRF-Fire in terms of computational requirements.

RESPONSE

The main benefit that we can think at this moment in terms of computational requirements is that the fire grid does not need to match the atmospheric grid. The fire grid could be much smaller. For example, one can run simulations over the Contiguous U.S. with UFS and simulate a fire in Colorado over a small domain like the one we show in the manuscript. This will introduce substantial computational savings. Also, the atmospheric grid could be complicated (e.g. unstructured), but the NUOPC cap will automatically perform the interpolation of variables between the two grids. We have highlighted these aspects: "*However, the region covered by the fire simulation in CFBM does not need to match the atmospheric domain allowing for using smaller fire domains which reduces the computational requirements of the fire model. Also, it is possible to have any kind of atmospheric grid (e.g., unstructured) and the NUOPC cap will perform the interpolation of variables automatically.*"

References

Andrews, P. L., 2018: The Rothermel surface fire spread model and associated developments: A comprehensive explanation, General Technical Report RMRS-GTR-371, US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO, U.S.A.

Eghdami, M., P. A. Jimenez y Munoz, and A. DeCastro, 2025: Sensitivity to the representation of wind for wildfire rate of spread: Case studies with the Community Fire Behavior model. Fire, 8, 135.

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