Fire Behavior model being coupled to the UFS

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With Acknowledgements to:
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Motivation

- Wildland fires produce large socio-economic impacts
- Accurate predictions of the fire spread can aid decision makers in mitigating the impacts
- Fire behavior models that account for the fire-atmospheric feedbacks can provide predictions in real time. The coupled model can be used for research in fire-weather interactions
- We have been developed a fire behavior model, the Community Fire Behavior model (CFBM), based on WRF-Fire, and couple it to UFS

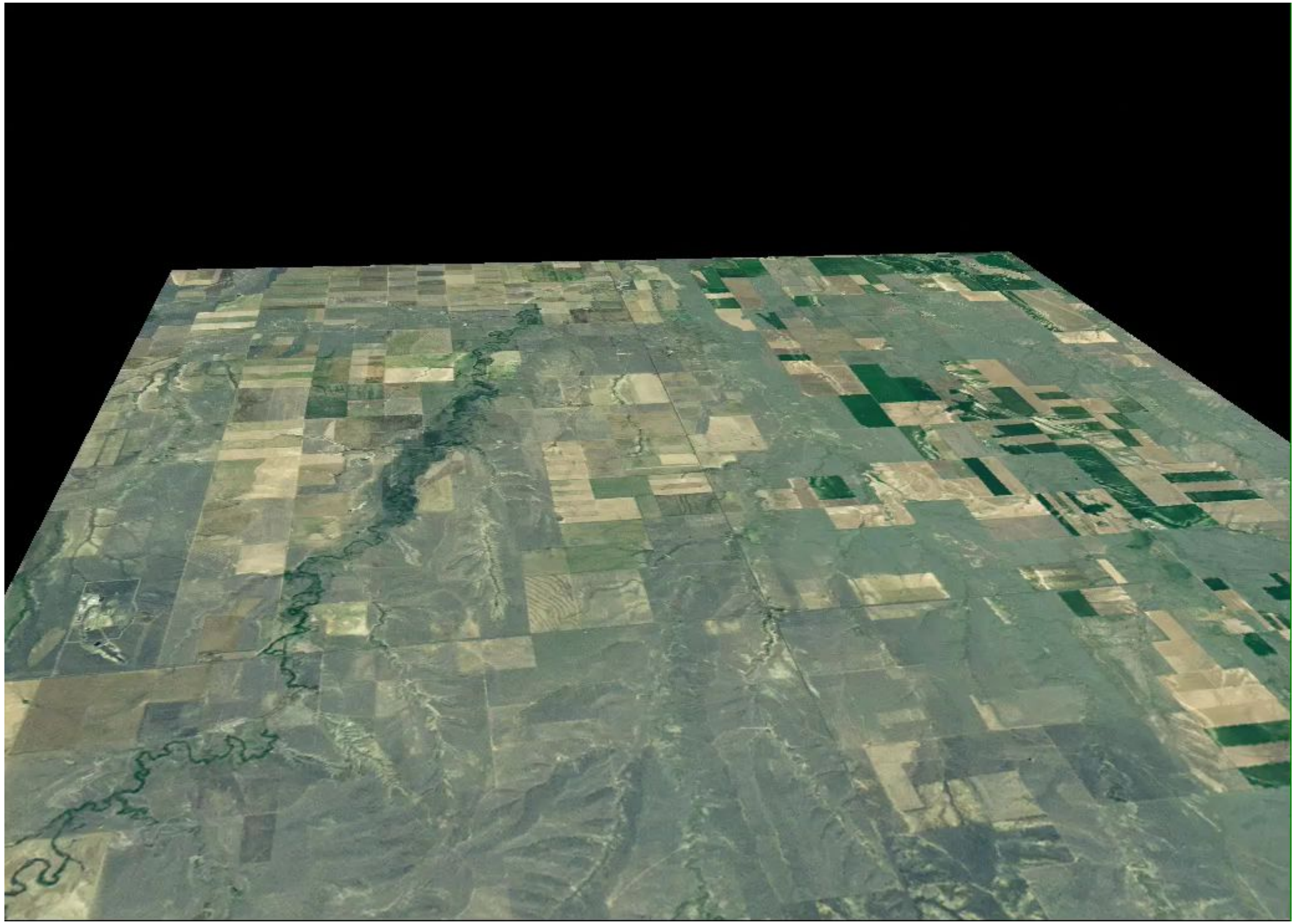
The WRF-Fire behavior model

Rate of spread of the fire parameterized as a function of the fuel characteristics, elevation, and near surface atmospheric variables.

New cells are ignited at the pass of the fire front releasing heat, moisture and smoke that feedback the atmosphere

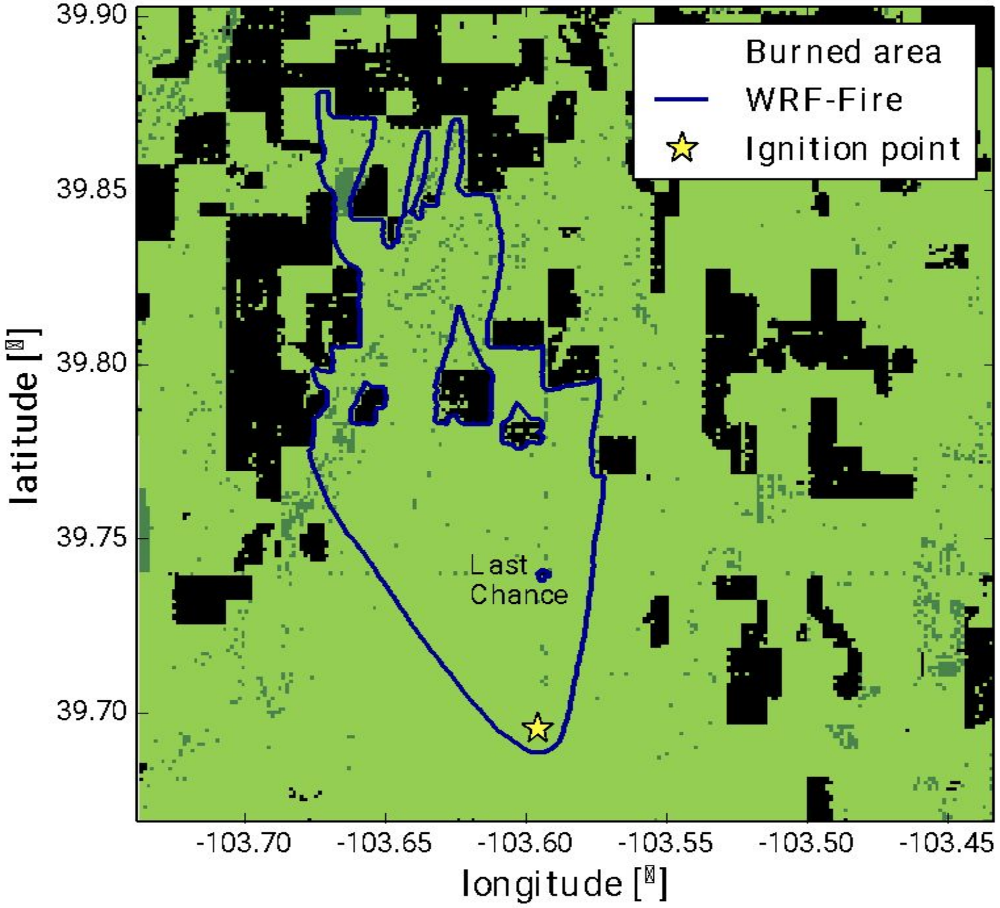
The WRF-Fire behavior model

The model captures fire-atmosphere interactions



Modeled fire perimeter reveals good agreement with observation

Munoz-Esparza et al. JAMES 2018



The Community Fire Behavior model (CFBM)

- The Community Fire Behavior model (CFBM) was developed to provide a fire behavior model to NOAA's Unified Forecast System (UFS)

- The fire behavior model is based on WRF-Fire version 4.3.3

- The coupling with the atmosphere is done via the Earth System Modeling Framework (ESMF) library. This requires having the fire behavior model in a National Unified Operational Prediction Capability (NUOPC). The NUOPC requires subroutines to initialize and advance the fire behavior, and to define the grid and variables that can be imported/exported (NUOPC cap). This allows for coordination for advancing the earth system components via the ESMF library.

- The CFBM can run…

… **offline** using the atmospheric state from an existing simulation (originally used for comparison with WRF)

… **online**, coupled to an atmospheric host, UFS or WRF so far.

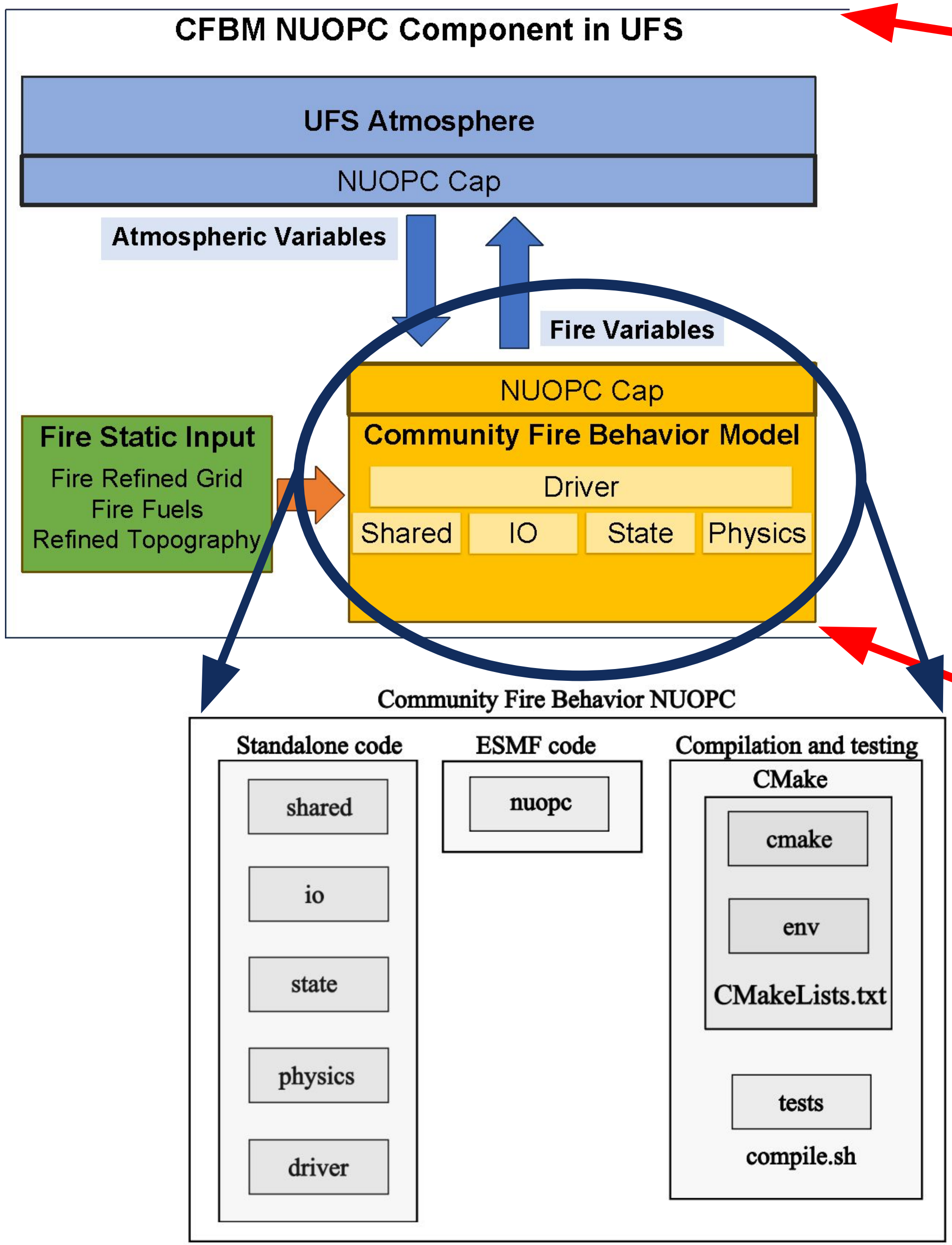
… there is a capability to perform **idealized** simulations via the namelist.

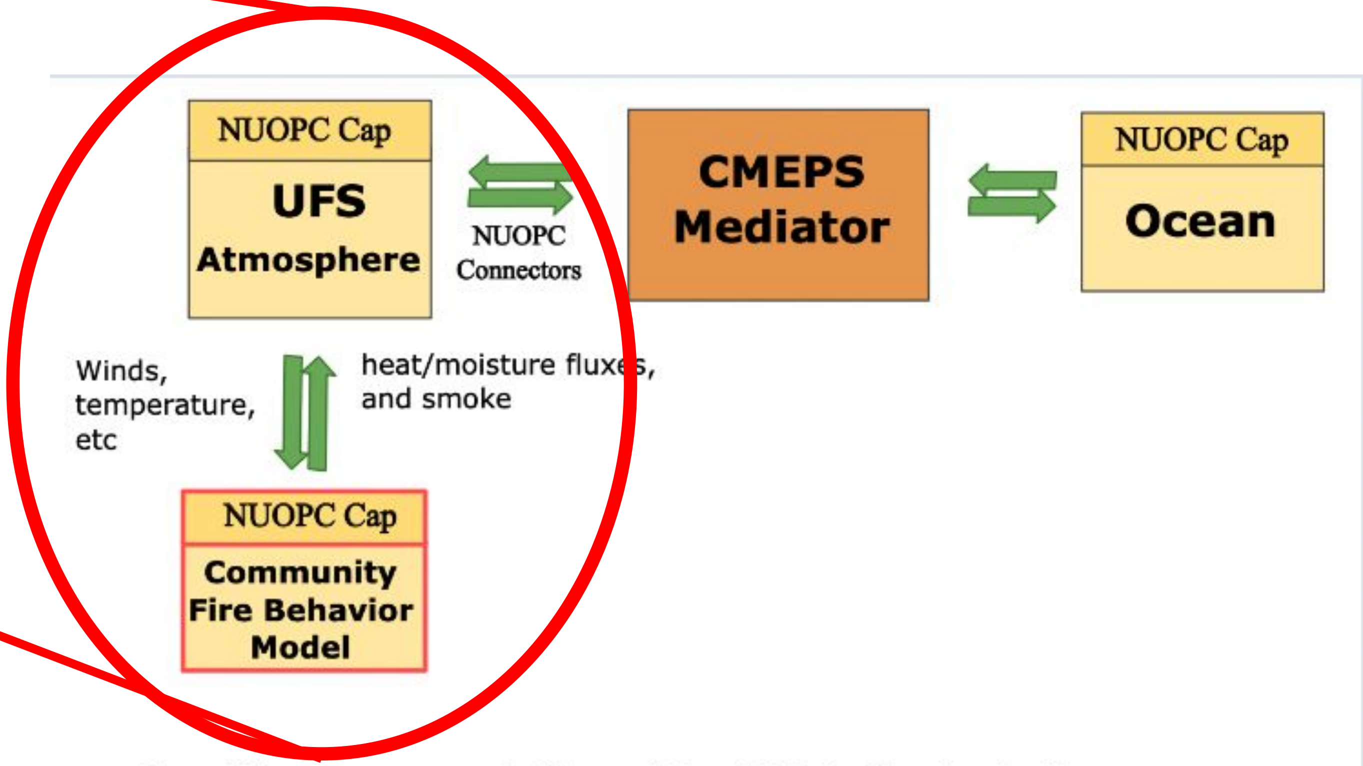
The Community Fire Behavior model

The WRF-Fire code was reorganized and enhanced to

- Remove atmospheric dependencies within the fire code
- Code reorganization to create a standalone model and clarify the logic of what is being done
- Improved coding practices (e.g., consistent format across modules, impose implicit none statement, functions declared as pure when possible, eliminate variables that are passed but not used)
- Some processes are implemented as parameterizations controlled via the fire namelist. The parameterizations are implemented as abstract derived types that are extended
  - Rate of spread
  - Fuel model
  - Fuel moisture model
- Self-documented code
- OpenMP parallelization (MPI should follow)
- The code conforms to the Fortran 2008 standard
- Unexpensive automatic test available while doing developments. Regression tests in the Github repository automatically triggered upon PRs

Implementation of the fire behavior model in the UFS

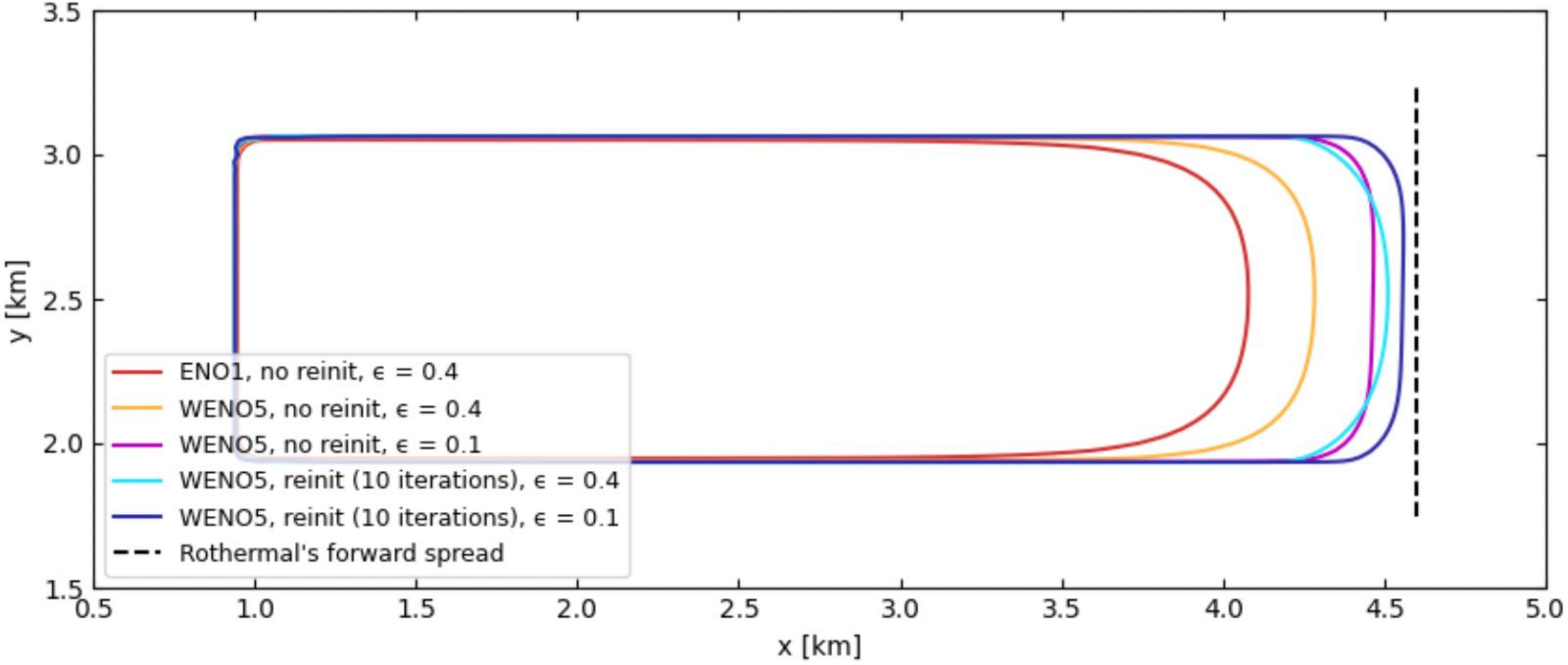




Simplified representation of the UFS to illustrate the coupling with the Community Fire Behavior Model NUOPC.

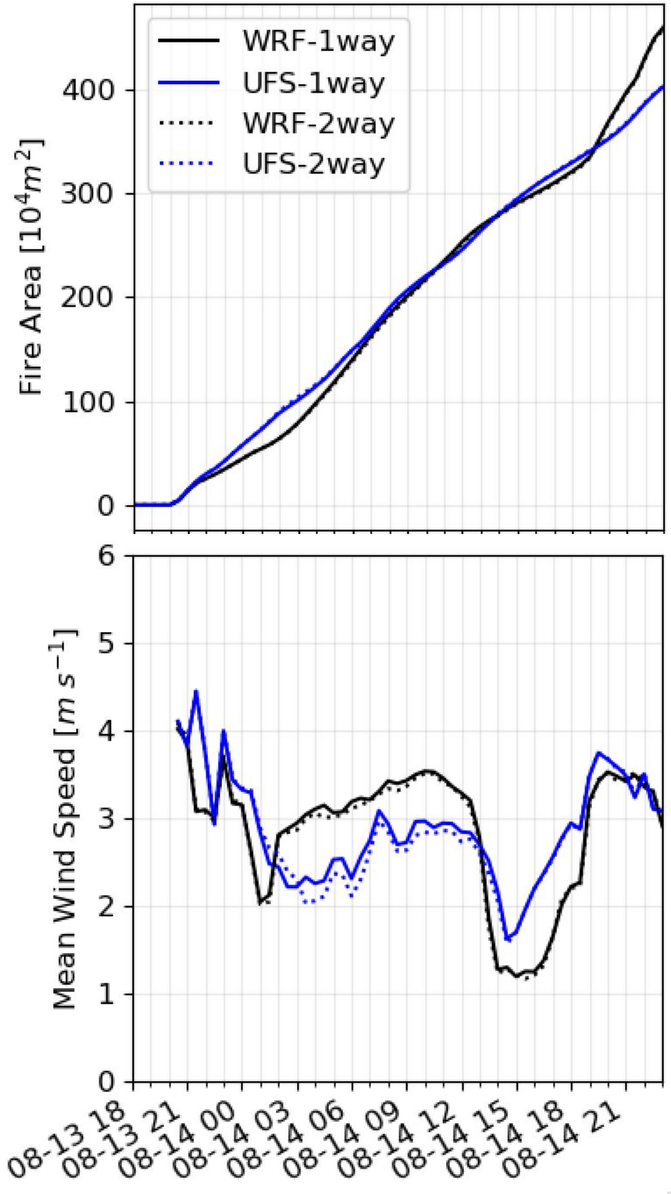
https://github.com/NCAR/fire_behavior

Idealized simulations: Exploring numerical methods

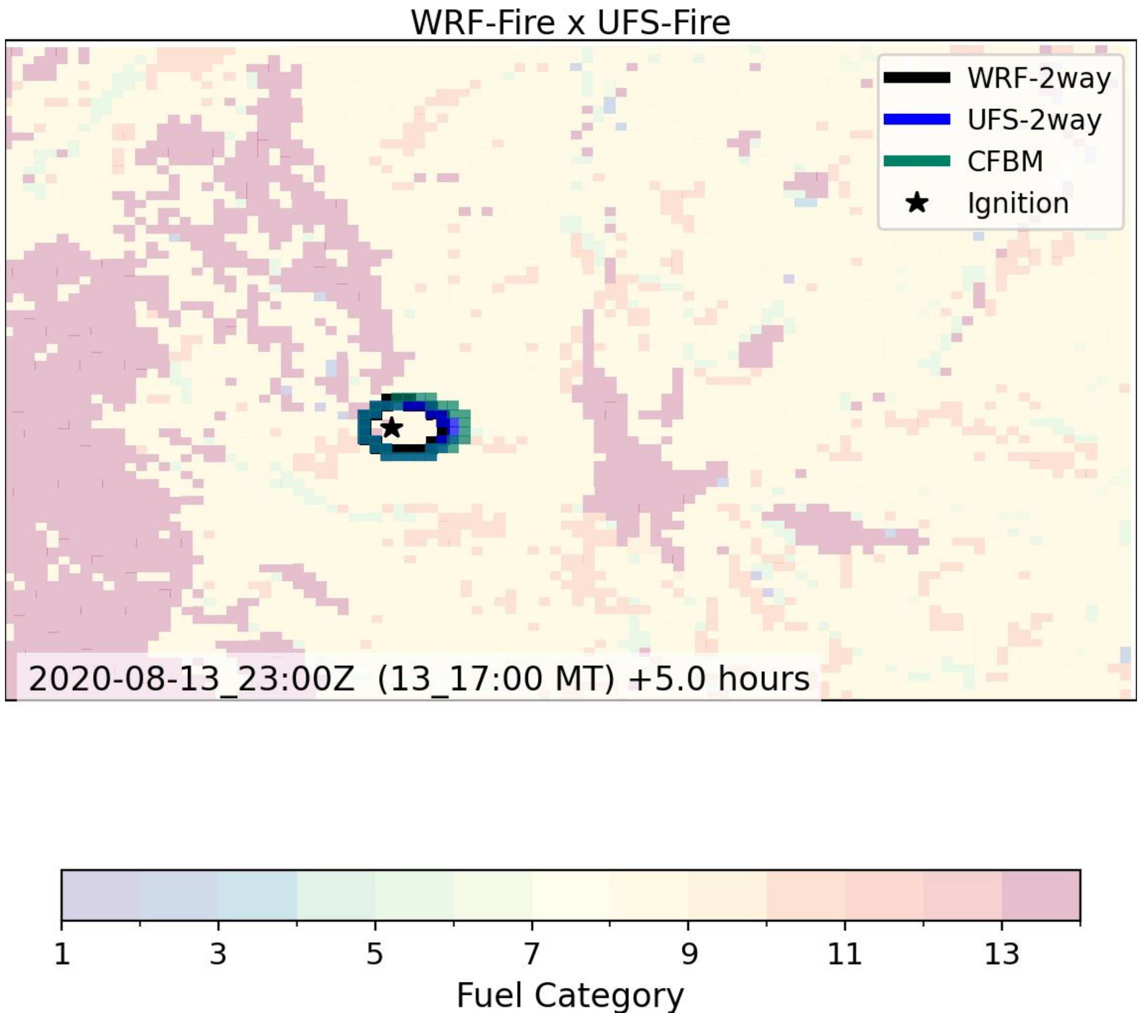


Real simulations: Ensuring consistency between WRF-Fire and the UFS-CFBM

Equivalent configuration of WRF-Fire and UFS-CFBM for the Cameron Peak fire (Colorado, USA)

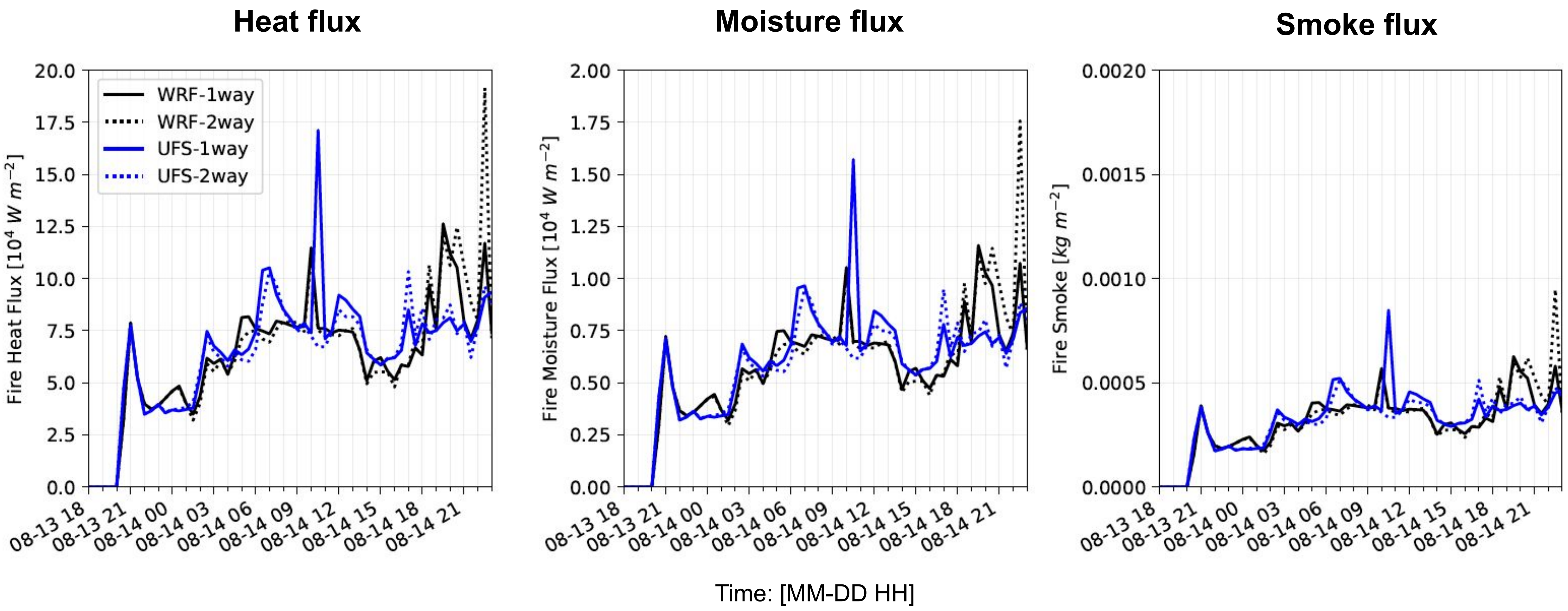


Technical description of the model:
https://gmd.copernicus.org/preprints/gmd-2024-124/



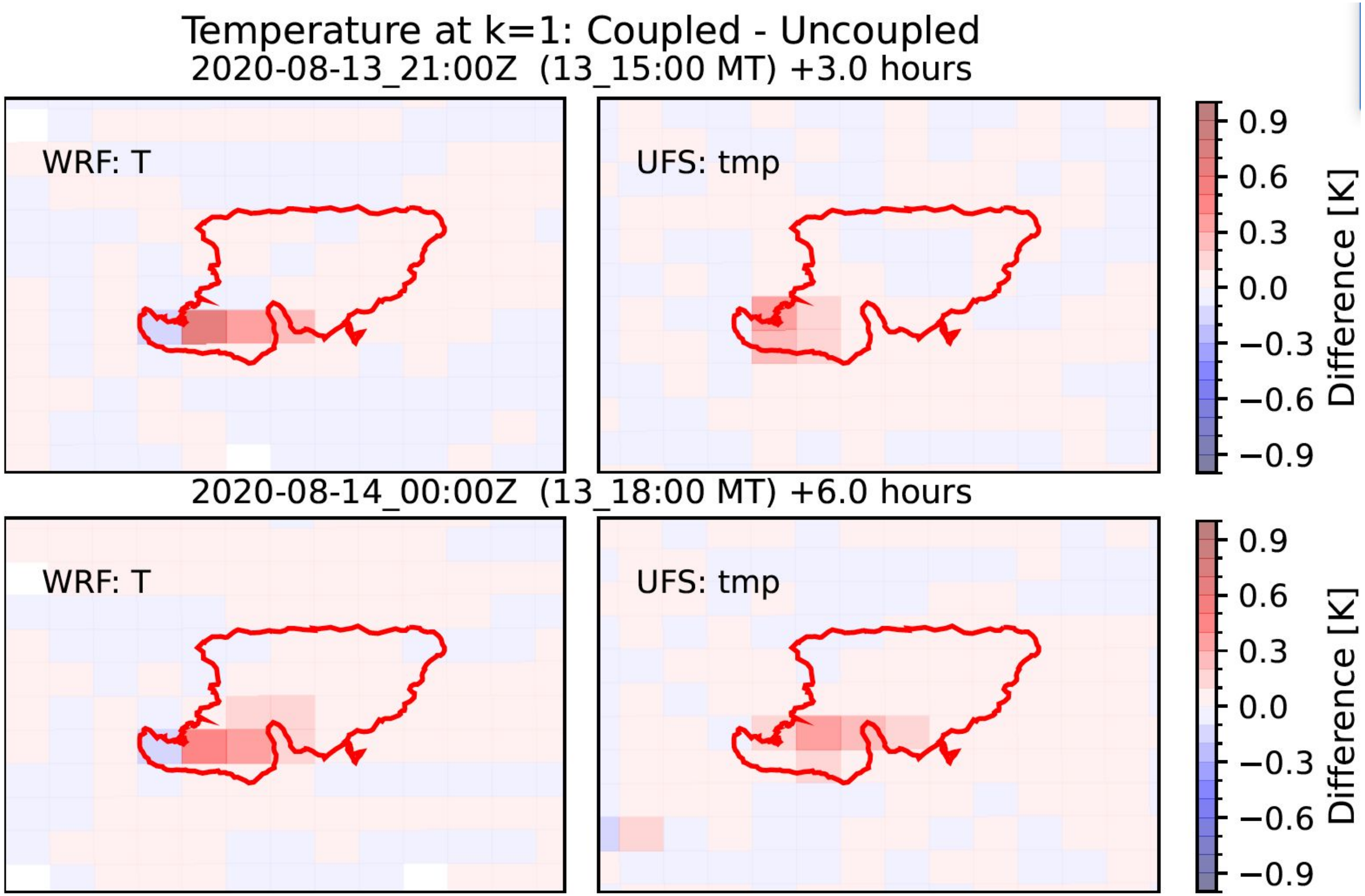
Real simulations: Ensuring consistency between WRF-Fire and the UFS-CFBM

Consistency in the evolution of the simulated fire fluxes from WRF-Fire and UFS-CFBM



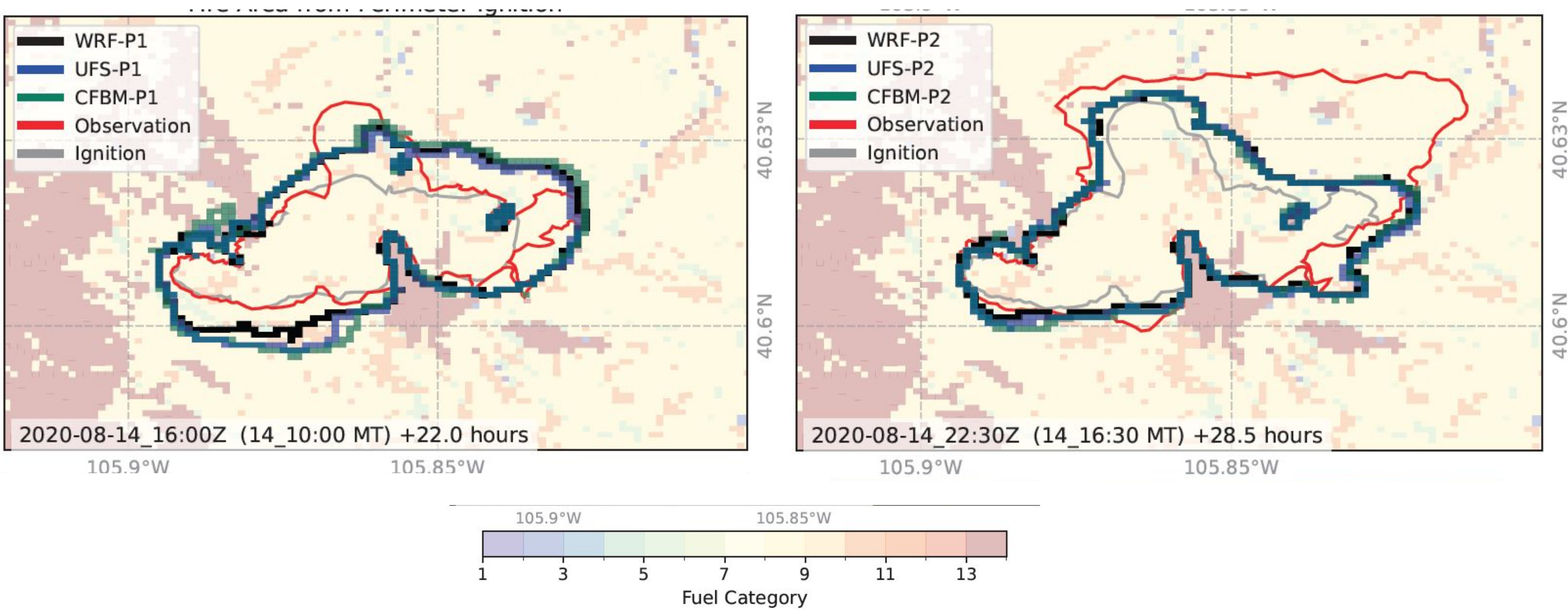
Real simulations: Ensuring consistency between WRF-Fire and the UFS-CFBM

Consistency between UFS and WRF in the fire impacts on the near surface temperature



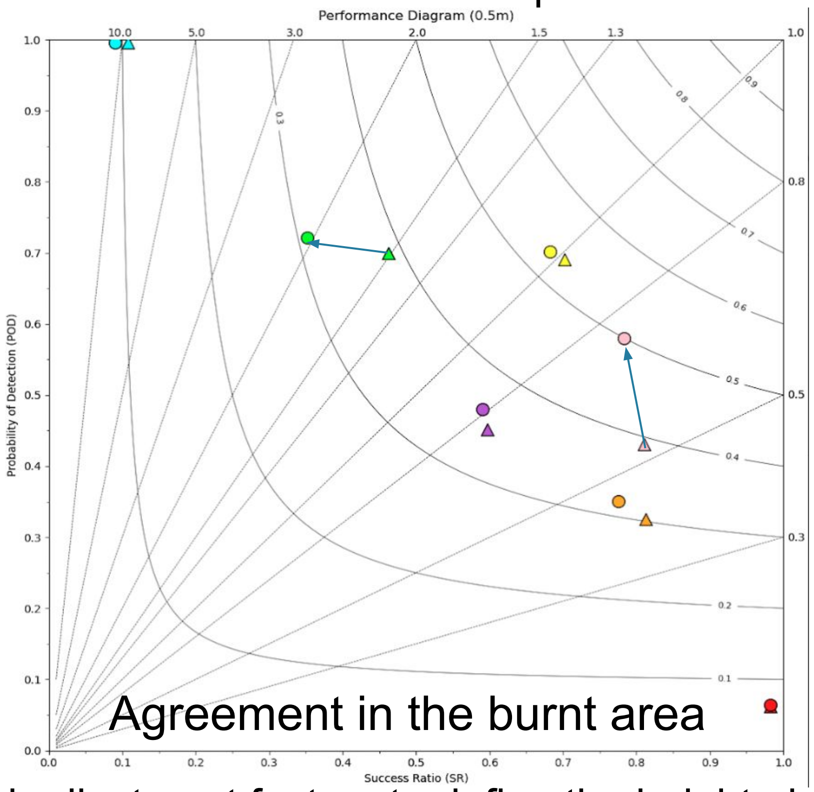
Real simulations: Ensuring consistency between WRF-Fire and the UFS-CFBM

Consistency between UFS and WRF in the fire area evolution in simulations starting from a given fire perimeter



Beyond WRF-Fire: Developments of the Community Fire Behavior model

- Impacts of the FMC in the fire rate of spread



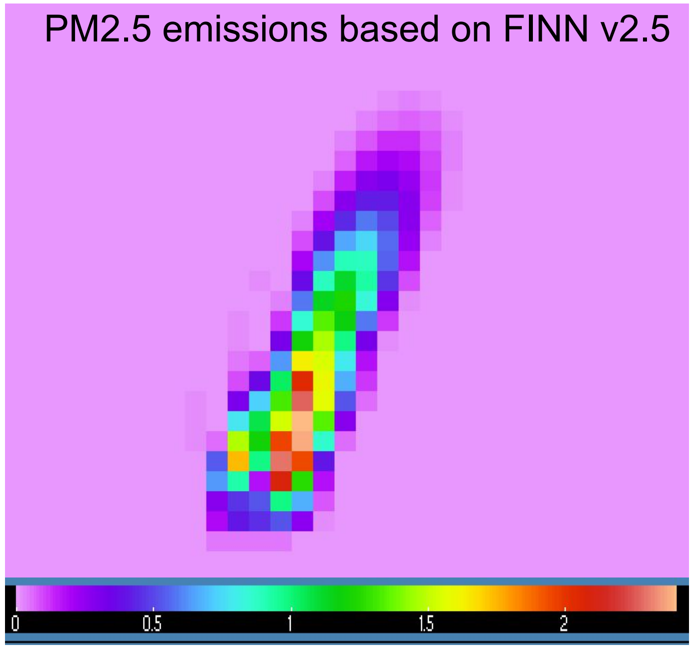
The triangles represent the results using the default FMC, 8%, whereas the circles represent the results using the retrieved FMC

- Using wind adjustment factors to define the height above ground level of the winds that drive the fire progression

Eghdami et al., Fire (2025): https://www.mdpi.com/2571-6255/8/4/135

- Calculations of the smoke optical depth. Similar to RRFS smoke. Acknowledgements to R. Ahmadov and E. James (NOAA/GSL).
- Fire emissions modulated by the fuel moisture content (ongoing). Acknowledgements to W. Tang (NCAR/ACOM)
- Improve the accuracy of the level set method in tracking the location of the fire perimeter (ongoing)

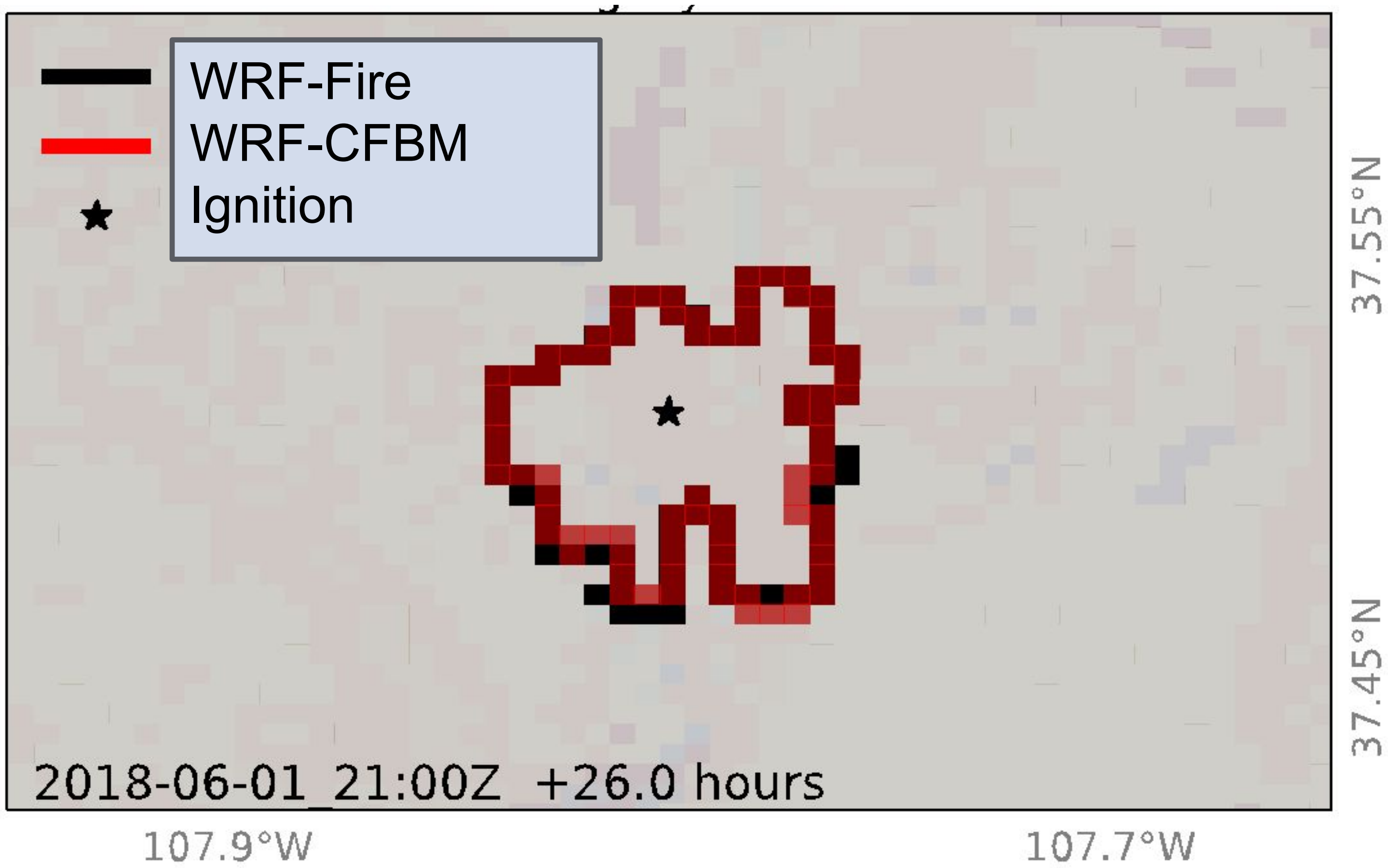
AOD from the smoke in WRF-CFBM



AOD PM2.5 550nm [-]

The Community Fire behavior model coupled to WRF

- Integration with WRF makes use of the flexibility provided by the modularity of the code
- Highly orthogonal code to mimic NUOPC philosophy
- Consistency between the evolution of the fire perimeter from WRF-Fire and CFBM



The Community Fire Behavior Model's vision

Vision: Make the Community Fire Behavior model available to a variety of atmospheric hosts to foster collaborative developments in order to increase our fundamental understanding of fire science and minimize the adverse impacts of wildland fires

- Implemented in community UFS model (NUPOC). Code already publicly available.
- Implemented in WRF taking advantage of the CFBM modularity
- Coupling to the Model for Prediction Across Scales (MPAS) should follow. Coupling via NUOPC straightforward once MPAS is available as a NUOPC component in UFS

Possible to run UFS-CFBM via the Short Range Weather Application

- Possible to run coupled fire-atmosphere simulations using the UFS Short Range Weather application. The SWRApp automatically generates the fire namelist via UFS configuration files.
- An easy interface for running experiments and a new capability for UFS operations, science, and research
- Support on multiple platforms
- Access to all the extended capabilities of the SRW App (e.g. verification)
- Expanded audience of users and potential contributors

Documentation

Model's website: https://ral.ucar.edu/model/community-fire-behavior-model

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Documentation: Configuring CFBM

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2. Configuring the Community Fire Behavior Module

2.1. Configuring a domain with the WRF Pre-processing System (WPS)

Because the CFBM was originally developed as part of the WRF model, creating a domain must be done using the WRF Pre-processing System (WPS). These instructions can be found in the WRF Users Guide. To run the CFBM with the UFS or with WRF data, users need to provide a geo_em.d01.nc file containting the interpolated static data fields.

Future releases will include a method for creating domains without needing to compile WPS.

2.2. Namelist Configuration

The options specific to the CFBM are controlled by a namelist file `namelist.fire`. This namelist file consists of three sections: `&time`, `&atm`, and `&fire`. The available options in each section are described below.

Example namelists can be found in the various test subdirectories under the `tests/` directory.

2.2.1. &time

`start_year`: *integer* (**Required**)
Start year of the simulation.

`start_month`: *integer* (**Required**)
Start month of the simulation.

`start_day`: *integer* (**Required**)
Start day of the simulation.

`start_hour`: *integer* (**Required**)
Start hour of the simulation.

`start_minute`: *integer* (**Required**)
Start minute of the simulation.

`start_second`: *integer* (**Required**)

Geogrid

The geogrid executable acts exclusively on static data sets (those that do not change from day to day) such as surface elevation and land use. Because these data sets are static, they can be obtained as a single set of files from the main WPS distribution website in resolutions of 10 minutes, 2 minutes, and 30 seconds. The geogrid executable extracts from these global data sets what it needs for the current domain. While resolutions of this magnitude are acceptable for ordinary atmospheric simulations, these data sets are too coarse for a high-resolution fire simulation. In particular, a WRF-Fire simulation requires two additional data sets not present in the standard data.

NFUEL_CAT
The variable NFUEL_CAT contains Anderson 13 fuel category data. This data can be obtained for the US from the seamless data access server for *USGS LANDFIRE_*. Using the zooming and panning controls, the user can select the desired region with LANDFIRE 13 Anderson Fire Behavior Fuel Models box selected. This opens a new window where the user can request the data in specific projections and data formats.

ZSF
The variable ZSF contains high resolution terrain height information similar to that in the HGT variable present in atmospheric simulations; however, the standard topographical data set is only available at a maximum resolution of 30 arc seconds (about 900 meters). For a simulation using the WRF-Fire routines, data resolution of at least 1/3 of an arc second is desirable to include the effect of local terrain slope on the rate of spread. Such a data set is available for the US at from USGS' National Map seamless data access server. The desired data set on this server is listed under elevation and is called 1/3 arc-second DEM. 1 arc second data is also available at the same data server.

To set up the model is required to have:

- The geogrid file describing the fire domain using the WPS
- The fire model namelist file, i.e., namelist.fire, generated by the SRWApp automatically

Documentation: Setting up the SRWApp

3. Coupling to the UFS: Running the CFBM in the SRW

This schematic figure illustrates the integration of the Community Fire Behavior Model (CFBM) as a component within the Unified Forecast System (UFS) using the NUOPC (National Unified Operational Prediction Capability) framework.

The blue box at the top represents the UFS atmosphere component, which provides atmospheric variables (e.g., wind, temperature) to drive the fire model. The orange box represents CFBM that simulates fire spread and calculates heat, moisture, and fire smoke, which feed back into the atmospheric component. The NUOPC cap acts as an interface, facilitating the exchange of data between the UFS atmosphere and the CFBM. The CFBM requires static input in the form of geo_em.d01, which contains refined grids, fire fuels, and detailed topography to accurately simulate fire spread.

3.1. UFS Short-Range Weather Application (SRW)

The CFBM has been coupled to the UFS Weather Model for both one-way (atmosphere -> fire) and two-way coupled simulations. Simulations can be run using the UFS Short-Range Weather Application (SRW), a community-supported application for running numerical weather prediction simulations on limited-area domains. For information on using this capability, see the SRW Users Guide.

A preprint on scientific results using this new UFS Fire capability is available ([Jimenez y Munoz *et al.*, 2024]).

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2.10. Community Fire Behavior Module

2.10. Community Fire Behavior Module (UFS FIRE)

The Community Fire Behavior Model (CFBM) is a wildland fire model coupled to the UFS Atmospheric Model. The capability to run this code is now available in the UFS Short-Range Weather App for easy use by the community. The fire_behavior repository is a submodule of the UFS Weather Model (WM), coupled through the NUOPC Layer to provide direct feedback between the simulated atmosphere and the simulated fire. More information about the CFBM can be found in the CFBM Users Guide.

The biggest difference between the UFS FIRE capability and other modes of the UFS SRW is that a special build flag is required to build the coupled fire behavior code, as described in the instructions below. Aside from that, the need for additional input files, and some fire-specific config settings, configuring and running an experiment is the same as any other use of SRW.

Note

Although this chapter is the primary documentation resource for running the UFS FIRE configuration, users may need to refer to Chapter 2.3 and Chapter 2.4 for additional information on building and running the SRW App, respectively.

2.10.1. Quick Start Guide (UFS FIRE)

2.10.1.1. Download the Code

Clone the `develop` branch of the authoritative SRW App repository:

```
git clone -b develop https://github.com/ufs-community/ufs-srweather-app.git
```

2.10.1.2. Checkout Externals

Users must run the `checkout_externals` script to collect (or "check out") the individual components of the SRW App from their respective GitHub repositories.

```
cd /path/to/ufs-srweather-app/
./manage_externals/checkout_externals
```

2.10.1.3. Build the SRW App with Fire Behavior Enabled

To build the SRW with fire behavior code, use the following command:

```
./devbuild.sh -p=<machine> -a=ATMF
```

where `<machine>` is `hera`, `derecho`, or any other Tier 1 platform. The `-a` argument indicates the configuration/version of the application to build; in this case, the atmosphere-fire coupling (ATMF).

If UFS FIRE builds correctly, users should see the standard executables listed in Table 2.3. There are no additional files expected, since the CFBM is coupled to the UFS weather model via the same `ufs_model` executable.

2.10.1.4. Load the `srw_app` Environment

latest

2.10.1.7. Specifying a fire ignition

The CFBM simulates fires by specifying an "ignition" that will then propogate based on the atmospheric conditions and the specified settings. An ignition can either be a "point ignition" (i.e. a disk of fire some specified radius around a single location), or a straight line linear ignition specified by a start and end location and a specified "radius" (width). The ignition can start at the beginning of your simulation, or at some time later as specified. The CFBM can support up to 5 different fire ignitions at different places and times in a given simulation.

The CFBM settings are controlled by the namelist file `namelist.fire`. The available settings in this file are described in the CFBM Users Guide, and an example file can be found under `parm/namelist.fire`. However, there is no need to manually provide or edit this file, as the SRW workflow will create the fire namelist using the user settings in `config.yaml`. The fire-specific options in SRW are documented in Section 3.1.21.

2.10.1.8. Example fire configuration

Here is one example of settings that can be specified for a UFS FIRE simulation:

```
fire:
  envvars:
    UFS_FIRE: True
    FIRE_INPUT_DIR: /home/fire_input
  DT_FIRE: 0.5
  OUTPUT_DT_FIRE: 1800
  FIRE_NUM_IGNITIONS: 1
  FIRE_IGNITION_ROS: 0.05
  FIRE_IGNITION_START_LAT: 40.609
  FIRE_IGNITION_START_LON: -105.879
  FIRE_IGNITION_END_LAT: 40.609
  FIRE_IGNITION_END_LON: -105.879
  FIRE_IGNITION_RADIUS: 250
  FIRE_IGNITION_START_TIME: 6480
  FIRE_IGNITION_END_TIME: 7000
  FIRE_ATM_FEEDBACK: 1.0
```

Summary and Conclusions

- We have developed and coupled a fire behavior model, the CFBM, to UFS. Code already publicly available in UFS repositories (the Community UFS model, SWR App, CCPP, etc).

- Consistency between UFS and WRF simulations

- Coupled fire-atmosphere simulations can be run from the SRW Application

- Documentation available to activate the fire model in UFS

- Ongoing developments to go beyond WRF-Fire methods in the Community Fire Behavior model, and to couple it to other atmospheric hosts

Questions? jimenez@ucar.edu