A Fire-Spotting Parameterization Coupled with the WRF-Fire Model

Maria Frediani[1], Timothy W Juliano[1], Amy DeCastro[1], Branko Kosovic[1], and Jason Knievel[2]

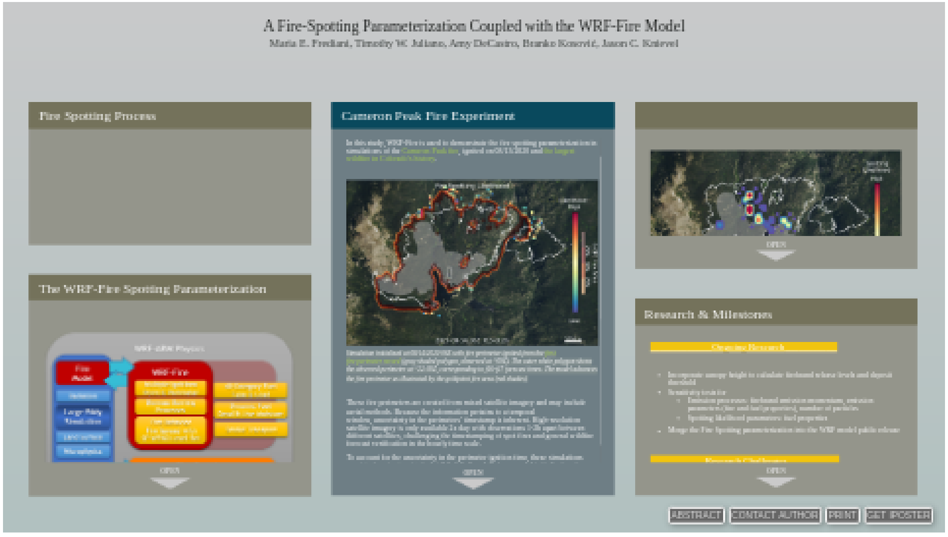
[1]National Center for Atmospheric Research
[2]NCAR

November 24, 2022

Abstract

A fire-spotting parameterization was developed for the WRF-Fire component of the WRF model version 4.0.1. The parameterization uses a Lagrangian particle transport framework and is coupled to the fire component of the WRF-ARW model as an independent Fortran module. When fires are active, the fire-spotting module identifies areas at risk of fire spotting by modeling transport and physical processes of individual firebrands released from fire locations. Firebrands are released at varying heights, from locations with higher emission potential, defined as a function of fire rate of spread and fuel load. Firebrands are transported with the atmospheric flow, and physical properties (temperature, mass, and terminal velocity) are updated at the default model timestep. The particles may either burnout before settling or deposit at a grid point when carried below a specified height threshold. The number and spatial distribution of deposited firebrands correspond to the flow-dependent risk component of new fire ignitions due to fire spotting. The flow-dependent component is then combined with the risk associated with local fuel properties (load and moisture) to yield the fire spotting spatial likelihood. In this presentation, the fire-spotting parameterization is assessed through a qualitative analysis of wildfires in Colorado. Uncertainties in fire ignition observations, used to initialize fires in the WRF-Fire model, often limit the ability to accurately model fire area, which in turn controls the firebrands' emission location. Limited spotting observations are also a challenge to an objective verification of the module skill. We expect that the most recent remote sensing products will improve the representation of surface properties and accuracy of ignition parameters for WRF-Fire, which will directly transfer to the fire-spotting module capability. Direct enhancements to the parameterization may be incorporated into the module as laboratory experiments and field campaigns provide data to improve our ability to model firebrands' initial properties (e.g. firebrand size and ejection height) and physical processes (burnout and terminal velocity).

A Fire-Spotting Parameterization Coupled with the WRF-Fire Model



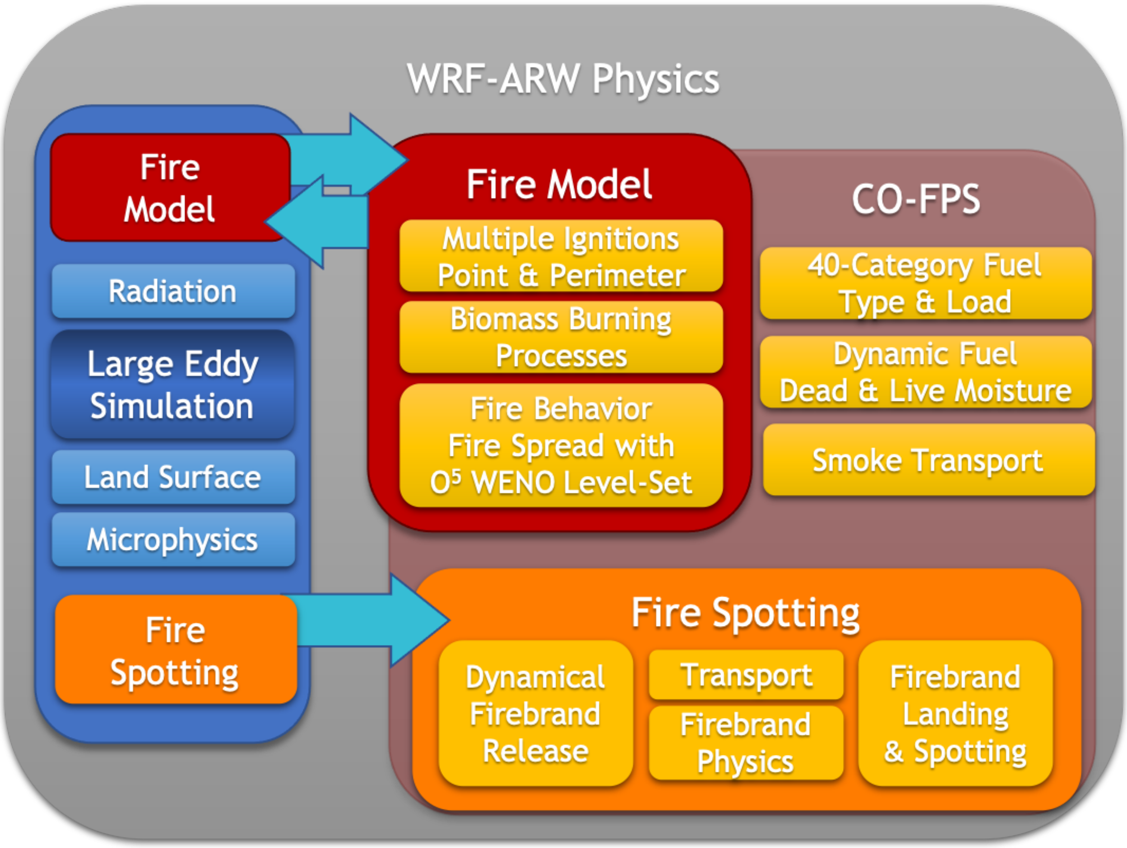
Maria E. Frediani, Timothy W. Juliano, Amy DeCastro, Branko Kosović, Jason C. Knievel

National Center for Atmospheric Research

PRESENTED AT:

AGU FALL MEETING
Online Everywhere | 1–17 December 2020

THE FIRE-SPOTTING PARAMETERIZATION

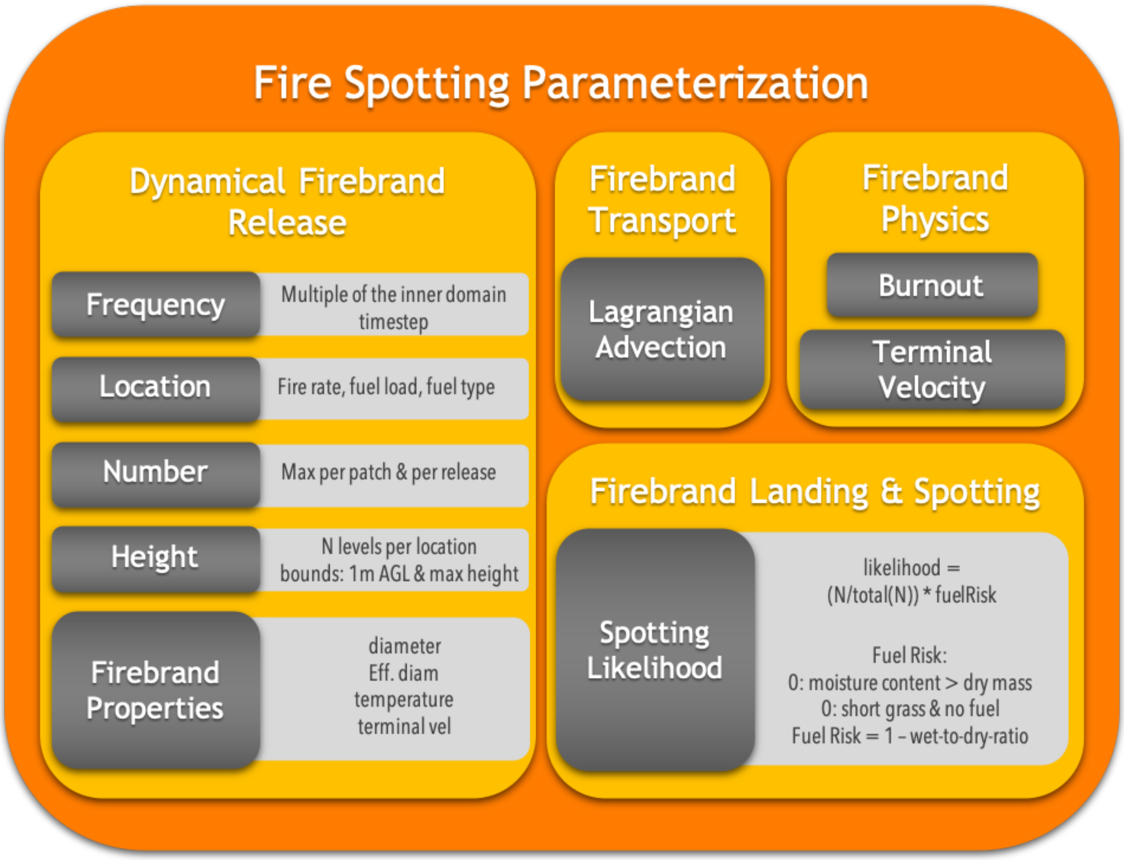


The WRF-Fire model framework with the Fire-Spotting parameterization.

The wildfire behavior model within the Weather Research and Forecasting (WRF) model parameterizes biomass burning processes and rate of fire spread from specified ignitions locations.

The Fire-Spotting parameterization releases firebrands at gridpoint locations along the fire front, from grid points with high fire rate-of-spread and denser fuel loads. Firebrands are released at multiple heights, transported with the atmospheric flow, and consumed by combustion. Firebrands that are not entirely consumed and land on unburned grid points outside the active fire source area are accumulated in a 2-D field during regular intervals.

A fire-spotting likelihood field is computed using the ratio of landing firebrands per gridpoint to the total number of landing particles within the corresponding time interval of model outputs. The ratios are then scaled by a relative measure, function of fuel load and moisture content at the landing grid points.



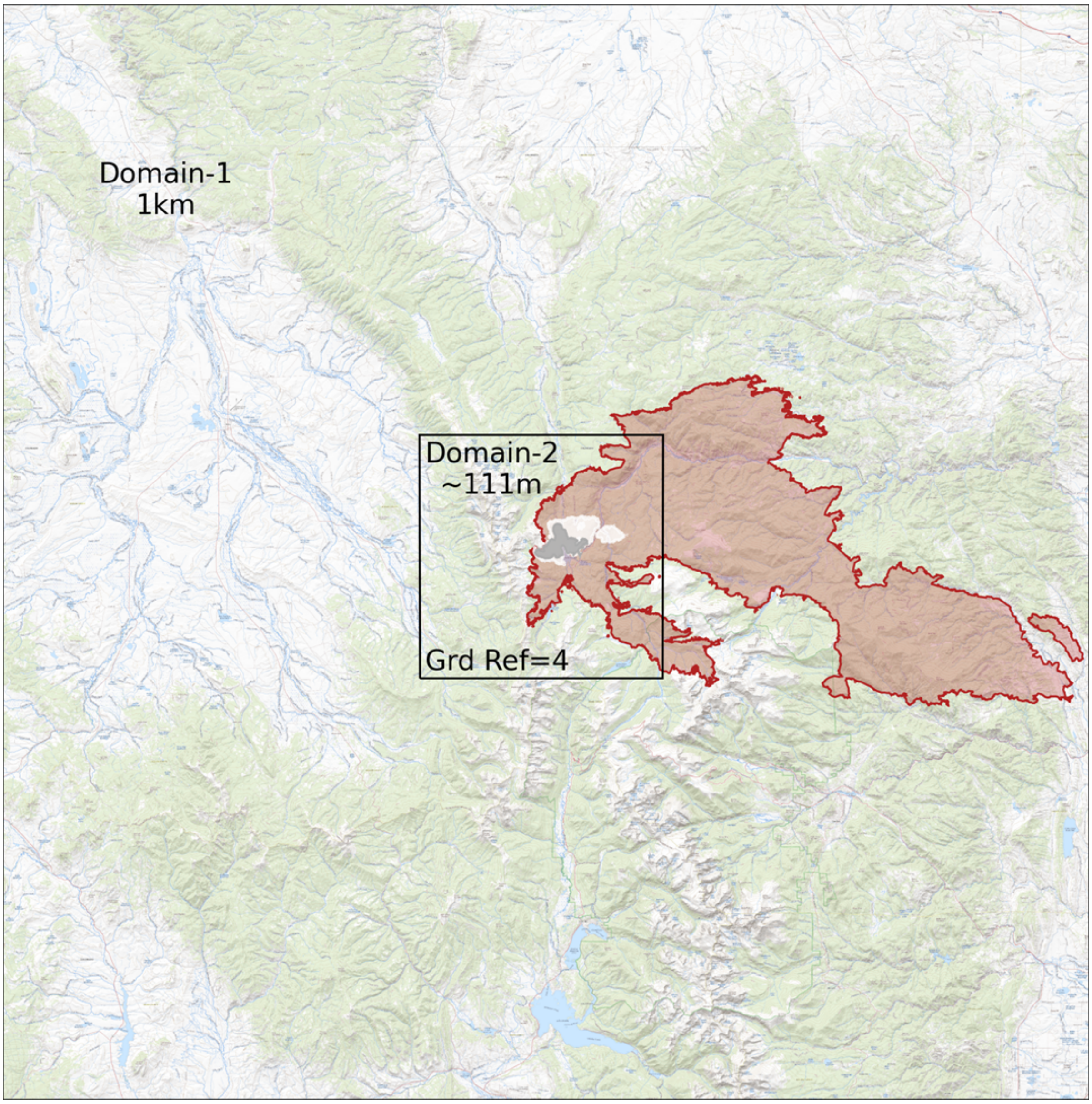
Features in Fire-Spotting parameterization.

The parameterization runs in the atmospheric model inner domain using a large-eddy simulation (LES) to resolve boundary layer processes, including turbulence and fire-induced convection. The model codebase used in this study contains the most recent development implemented onto the Colorado Fire Prediction System (CO-FPS), including a 5th-order WENO level-set method for fire perimeter propagation, 40-category fuel type and load, dynamic fuel moisture, and the fire spotting likelihood parameterization.

The fire-spotting processes are integrated according to the inner model domain dimensions and timestep. Data arrays from WRF-Fire stored on the refined grid mesh are used with their refined resolution to calculate firebrand release points and rescaled to the atmospheric inner grid for spotting likelihood.

CAMERON PEAK FIRE SIMULATIONS

The Fire-Spotting parameterization is demonstrated with simulations of the Cameron Peak fire (https://inciweb.nwcg.gov/incident/6964/). The fire started on 08/13/2020 approx. 2 PM MDT on the Arapaho and Roosevelt National Forests, west of Chambers Lake, and has become the largest wildfire in Colorado's history (https://www.coloradoan.com/story/news/2020/11/17/cameron-peak-fire-colorados-largest-wildfire-damages-homes-landscape/6212902002/). The fire was contained on 12/05/2020 with an estimated area of ~209 Acres.



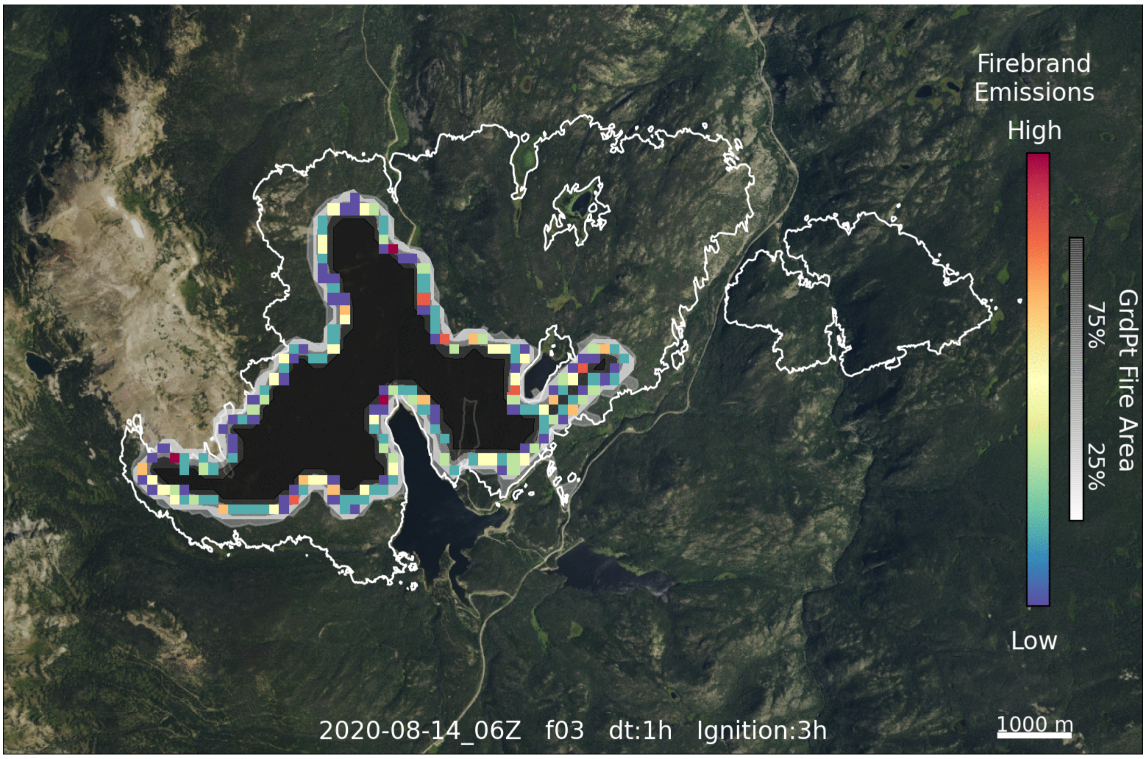
The figures and animations for this study were made from simulations initialized at 08/14/2020 06Z, integrated for 24 hours, with fire ignited from the first perimeter record (http://inciweb.nwcg.gov/photos/COARF/2020-08-14-0842-Cameron-Peak/picts/2020_08_15-08.11.04.196-CDT.png) (illustrated in gray, observed at ~09Z). The figures include an outer white polygon representing the observed perimeter at ~22:30Z*, corresponding to f16-f17 forecast times (hours after initialization). The final fire estimated area is displayed with the simulation domain for reference only (in red).

Footnotes

*Although the reference perimeter is timestamped at 22:30Z (white polygon), Suomi and NOAA-20 satellite fire products indicate that the spot fire east of the State Highway CO-14 was likely at its early stage by 20-21Z.

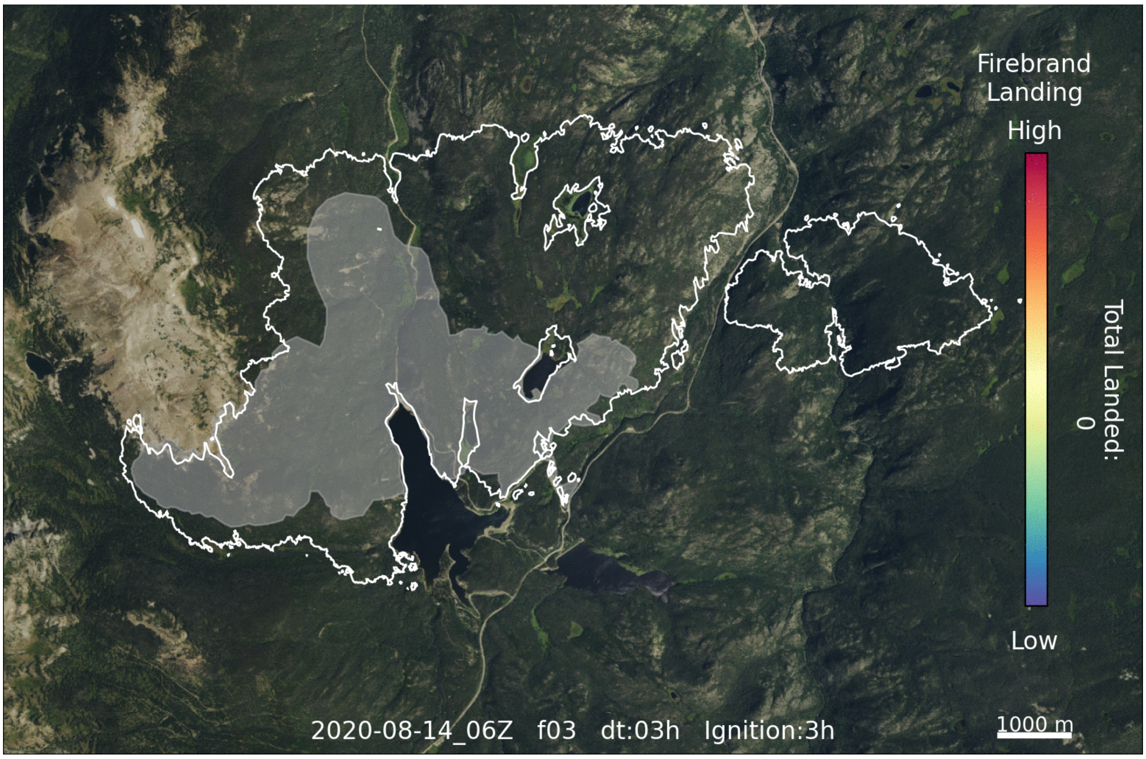
FIRE-SPOTTING SIMULATION EXPERIMENT

_Firebrand Release___________________



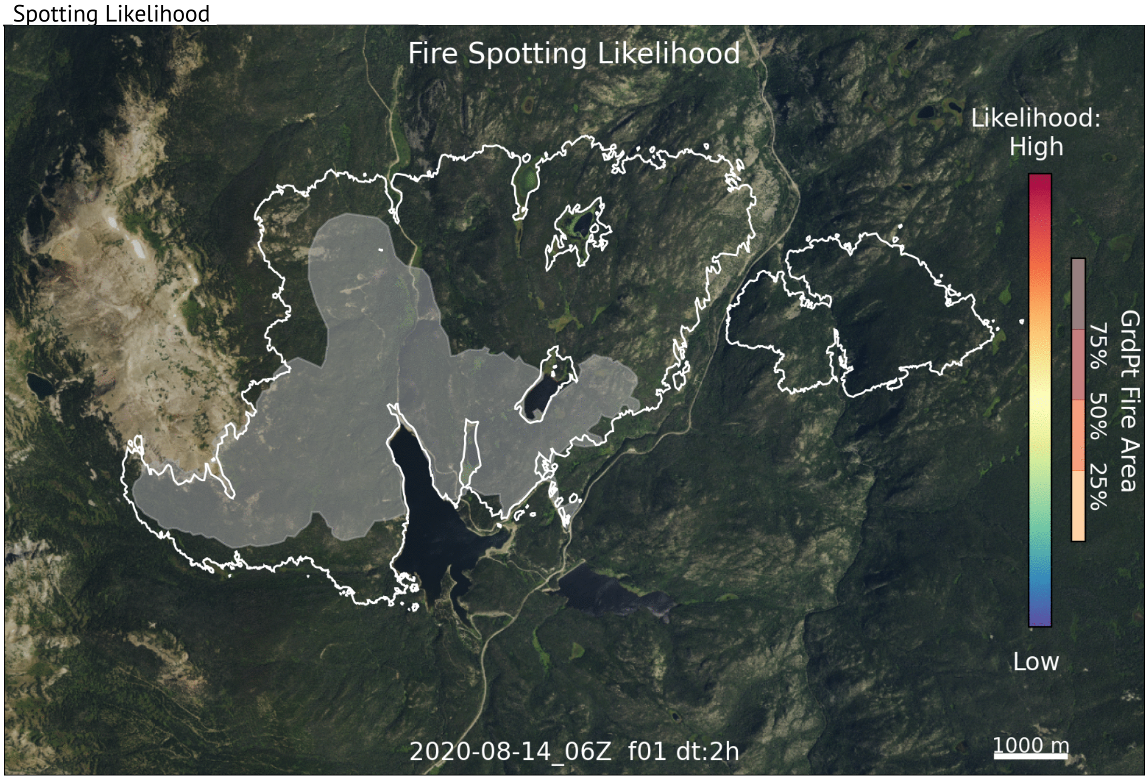
Firebrands are released from the gridpoints along the fire front with the highest fire rate of spread and dry fuel load.

_Firebrand Landing___________________



Firebrands often land on neighboring gridpoints with active fire and are intentionally excluded in the spotting likelihood product.

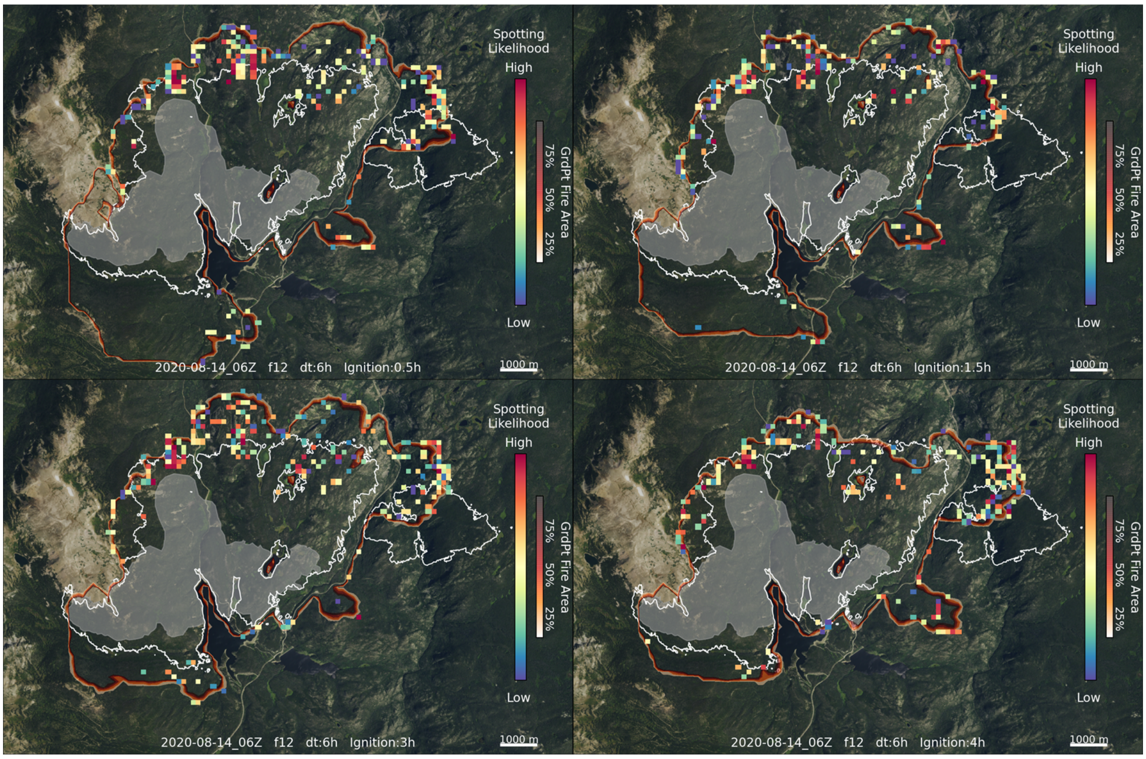
Spotting Likelihood



Fire-Spotting likelihood field combined in 2-hour intervals.

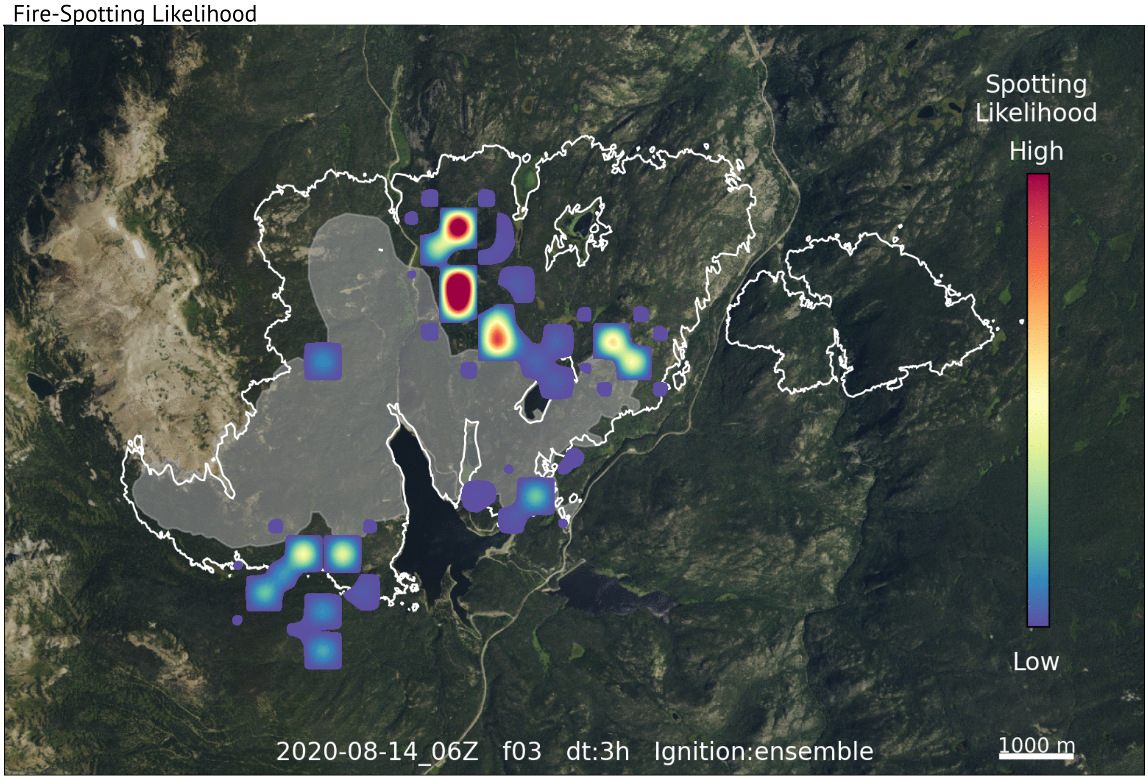
FIRE-SPOTTING FORECAST ENSEMBLE

A set of simulations with varying ignition times was used as a 4-member ensemble to account for the uncertainty in the perimeter ignition time**. The ensemble members show multiple clusters with high fire spotting likelihood. All of the ensemble members indicate a high likelihood for spot fires in the region across the containment barriers (east of State Highway CO-14 and Cache La Poudre River.

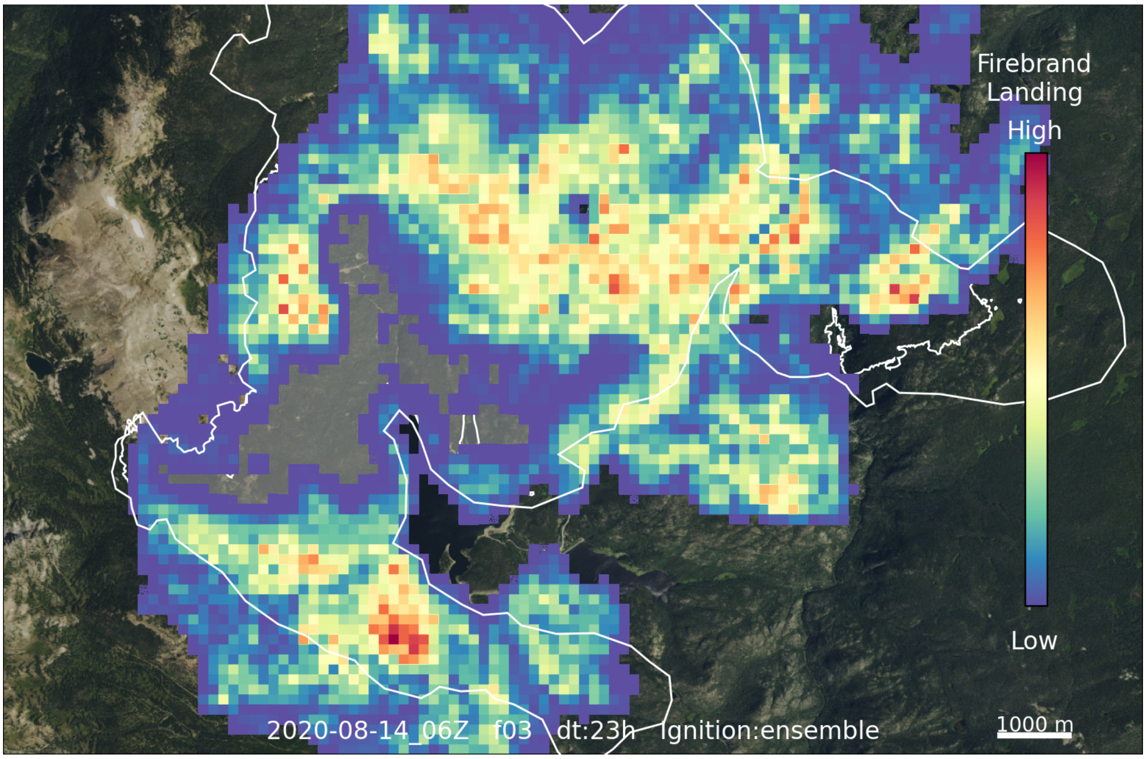


Relative fire spotting likelihood accumulated for a 6-hour period starting at 08/14 18Z (12 PM MDT) with the fire area representing the perimeter forecast by the end of the interval, at 08/14 21Z (6 PM MDT). The panel shows the four ensemble members with fire perimeter ignited at 0.5, 1.5, 3, and 4h from model initialization time (6:30, 7:30, 09, 10Z, resp.)

Fire-Spotting Likelihood



_Firebrand Landing_____________________



_________________Footnotes________________

**The fire perimeters are created from mixed satellite imagery and often include additional aerial methods. Because the information pertains to a temporal window, uncertainties in the perimeters' timestamps are inherent. High-resolution satellite imagery is only available 2x day with observations 1-2h apart between different satellites, challenging the timestamping of spot fires and general wildfire forecast verification in the hourly time scale.

RESEARCH & MILESTONES

Challenges & Milestones

Model development challenges are mostly due to firebrand unknowns:

- Emission properties (size, mass, temperature)
- Burnout physics

Model verification challenges include:

- Uncertainties
  - Atmospheric component (e.g. wind speed and direction)
  - Fire behavior processes
- Data scarcity and inconsistencies
  - Fire spotting observations
  - Frequency and resolution of perimeters with reliable timestamps

---

To improve resilience, preparedness, and response to wildfire disasters, researchers, stakeholders, and communities need a robust wildfire and spotting model.

Collaborations and partnerships are fundamental to overcome current challenges to develop a community model and verify wildfire forecasts.

Ongoing Research

- Incorporate canopy height to calculate firebrand release levels and deposit threshold
- Sensitivity tests for
  - Emission processes: firebrand emission momentum, emission parameters (fire and fuel properties), number of particles
  - Spotting likelihood parameters: fuel properties
- Merge the Fire Spotting parameterization into the WRF model public release

Acknowledgements

Funding was provided by the State of Colorado through the Center of Excellence for Advanced Technology Aerial Firefighting, Division of Fire Prevention and Control, and by the National Science Foundation, which sponsors NCAR.

Thanks to Brad Schmidt and Ben Miller (Center of Excellence for Advanced Technology Aerial Firefighting), Janice Coen (NCAR), and Representative Tracy Kraft-Tharp (Colorado General Assembly).

AUTHOR INFORMATION

I am a Project Scientist in the Research Applications Laboratory at the National Center for Atmospheric Research (RAL, NCAR). My research experience includes NWP modeling and parameterizations, deterministic and probabilistic forecast verification, forecast postprocessing, statistical modeling, model uncertainty, and cloud microphysics.

I developed the Fire-Spotting parameterization module for the WRF-Fire model in collaboration with Tim Juliano, who developed the firebrand physics processes and worked with me during the various testing phases. Tim and I joined the model development and assessment team in the final years of the Colorado Fire Prediction System (CO-FPS) project. Alongside Amy deCastro, Amanda Anderson, Pedro Jimenez, Branko Kosivic, and Jason Knievel, the team assessed model performance, developed, and implemented substantial advancements to the CO-FPS modeling system and WRF-Fire model.

ABSTRACT

A fire-spotting parameterization was developed for the WRF-Fire component of the WRF model version 4.0.1. The parameterization uses a Lagrangian particle transport framework and is coupled to the fire component of the WRF-ARW model as an independent Fortran module.

When fires are active, the fire-spotting module identifies areas at risk of fire spotting by modeling transport and physical processes of individual firebrands released from fire locations. Firebrands are released at varying heights, from locations with higher emission potential, defined as a function of fire rate of spread and fuel load. Firebrands are transported with the atmospheric flow, and physical properties (temperature, mass, and terminal velocity) are updated at the default model timestep. The particles may either burnout before settling or deposit at a grid point when carried below a specified height threshold. The number and spatial distribution of deposited firebrands correspond to the flow-dependent risk component of new fire ignitions due to fire spotting. The flow-dependent component is then combined with the risk associated with local fuel properties (load and moisture) to yield the fire spotting spatial likelihood.

In this presentation, the fire-spotting parameterization is assessed through a qualitative analysis of wildfires in Colorado. Uncertainties in fire ignition observations, used to initialize fires in the WRF-Fire model, often limit the ability to accurately model fire area, which in turn controls the firebrands’ emission location. Limited spotting observations are also a challenge to an objective verification of the module skill. We expect that the most recent remote sensing products will improve the representation of surface properties and accuracy of ignition parameters for WRF-Fire, which will directly transfer to the fire-spotting module capability. Direct enhancements to the parameterization may be incorporated into the module as laboratory experiments and field campaigns provide data to improve our ability to model firebrands' initial properties (e.g. firebrand size and ejection height) and physical processes (burnout and terminal velocity).

REFERENCES

Jiménez, P., D. Muñoz-Esparza, and B. Kosović, 2018: A high resolution coupled fire–atmosphere forecasting system to minimize the impacts of wildland fires: applications to the Chimney Tops II wildland event. Atmosphere, 9, 197, https://doi.org/10.3390/atmos9050197.

Muñoz-Esparza, D., B. Kosović, P. A. Jiménez, and J. L. Coen, 2018: An accurate fire-spread algorithm in the Weather Research and Forecasting Model using the level-set method. J. Adv. Model. Earth Syst., 10, 908–926, https://doi.org/10.1002/2017MS001108.

Parks, S. A., and J. T. Abatzoglou, 2020: Warmer and drier fire seasons contribute to increases in area burned at high severity in western US forests from 1985 to 2017. Geophysical ResearchLetters, 47, https://doi.org/10.1029/2020GL089858.

Scott, Joe H.; Burgan, Robert E., 2005: Standard fire behavior fuel models: a comprehensive set for use with Rothermel's surface fire spread model. Gen. Tech. Rep. RMRS-GTR-153. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO, 72 pages.

Skamarock, W. C., and Coauthors, 2008: Description of the Advanced Research WRF Version 3. NCAR Tech. Note NCAR/TN-475+STR, 113 pages.