The Firebrand Spotting Parameterizarion description for:

1. PR description (PR: pull request)

2. WRF Wildland Fire page (MMM WRF users webpage)

3. WRF-Fire chapter in the WRF-ARW User's Guide (Appendix A)

5. RAL's Fire page

Text formatting will follow the source.

1. PR description (PR: pull request)

(the most basic and brief description)

New module to parameterize firebrand spotting for WRF-Fire. This is a passive Lagrangian transport scheme to transport and burnout firebrands generated at the fire front. The scheme is activated when ifire == 2 by setting the namelist option fs_firebrand_gen_lim to an integer greater than zero (default is 0, i.e. scheme is off). It runs on dmpar and serial, in the inner nest (grid_id == max_dom). It was designed and tested using a mesoscale to LES domain configuration.

2. WRF Wildland Fire page (MMM WRF users webpage)

(also brief, but less technical and more descriptive, matching the page's content)

https://www2.mmm.ucar.edu/wrf/users/fire/wrf-fire.html
(where: at the bottom of the page, between the screenshot snippets in blue background)

> One time step of the fire model is performed for every WRF time step. The fire model runs on a refined grid, which covers the same region as the innermost WRF domain. The fire module supports both distributed and shared memory parallel execution.

The Firebrand Spotting parameterization is an optional module for WRF-Fire released in version 4.4 (April 2022). When users opt to generate firebrands, the parameterization identifies areas at risk of fire spotting by modeling the Lagrangian transport and physical processes of individual firebrands throughout the simulation starting at the fire ignition time. The parameterization was designed for high-resolution simulations and tested using large-eddy simulation (LES) in the innermost domain.

> See NCAR/RAL's WRF-Fire for Wildland Fire Modeling page for additional information.

3. WRF-Fire chapter in the WRF-ARW User's Guide (Appendix A)

https://www2.mmm.ucar.edu/wrf/users/docs/user_guide_v4/v4.3/users_guide_chap-fire.html
(where: new bullet after WRF-Fire Software, i.e. last 1st level bullet)

The Firebrand Spotting Parameterization

Introduction

The Firebrand Spotting parameterization was developed for WRF-Fire in WRF-ARW starting in version 4.4. The parameterization couples to WRF-Fire and uses a Lagrangian particle transport framework to advect firebrands in the innermost nest of the domain.

The parameterization identifies areas at risk of fire spotting by modeling transport and physical processes of individual firebrands, once fires have been ignited in the WRF-Fire model. The firebrand processes contained in the parameterization are Generation, Transport, Physics, and Landing

Firebrands are cyclically generated from sources along the fire front where fuel mass consumption is high. Distributed over multiple vertical levels, firebrands are transported with the resolved atmospheric flow and burnout as they are advected. Firebrands may burnout while in the air or land once trajectories descend below a given height threshold.

Particles that land before complete burnout are accumulated in a 2-D field. The field obtained from the spatial accumulation is used to calculate the likelihood of new fire ignitions due to spotting. The spotting likelihood is computed using the ratio of landed firebrands per gridpoint to the total number of landed particles within the corresponding time interval between consecutive model outputs. The ratios are then scaled by a function of dry over wet fuel mass at the corresponding gridpoints.

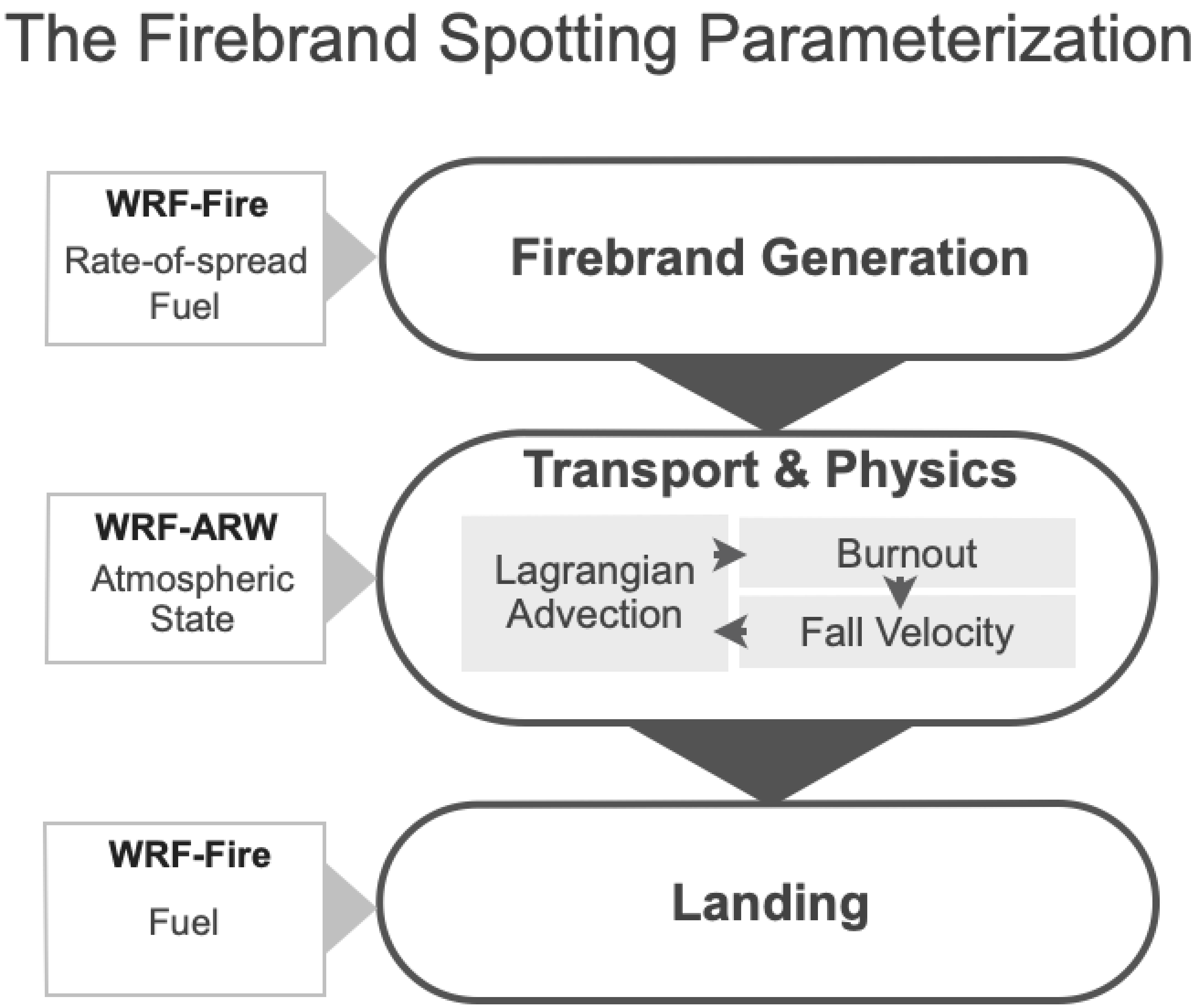

Fig 0: The Firebrand Spotting parameterization in the WRF-Fire model.

General Code Structure

The code comprises two independent modules, one with the physical processes (module_firebrand_spotting.F) and another with the necessary MPI wrapping routines (module_firebrand_spotting_mpi.F) to meet the required infrastructure layers of the code.

The Firebrand Spotting variables are part of registry.fire and the parameterization is called from start_em.F and solve_em.F, after all of the physics parameterizations and relevant halos are completed. Calculations made by the parameterization do not update external model variables and the parameterization only runs in the model inner nested domain, as defined by the condition grid_id == max_dom in start_em.F and solve_em.F.

Code Description

Firebrands are cyclically generated from sources along the fire front where fuel mass consumption is high. The frequency of generation cycles is defined by the generation frequency parameter and generation sources comprise the 2-D gridpoints actively burning in the given timestep, with the highest fuel mass consumed by fire between the given and previous generation cycles. The number of generation sources is defined by the Source Limit parameters, while the vertical levels per source are set by the Levels parameters (parameters are listed on the namelist table). Once the 3-D release position and initial properties of individual particles are established, firebrands are allowed to acquire momentum before particles begin to burnout.

During transport, firebrands follow the atmospheric flow, burnout, and descend. Particle density and char density are the only user-defined parameters used for firebrand physics. Firebrands may burnout entirely during transport, reach a maximum allowed lifetime, or land, as specified by the firebrand Landing parameters.

Particles that land are accumulated in a 2-D field (**fs_count_landed_all**). The spotting likelihood (**fs_spotting_lkhd**) is calculated for accumulation periods defined by the interval between outputs. The likelihood is computed at the end of the accumulation period, using all particles that land on an entirely unburnt gridpoint at the time when it reached the landing height threshold, according to the gridpoint boundaries of the atmospheric grid mesh (**fs_count_landed_hist**). A fractional value (**fs_frac_landed**) is computed as the number of particles per gridpoint to the total number of landed particles over the corresponding period and domain. The fractions are then scaled by a function of dry-over-wet fuel mass at each gridpoint (**fuel_spotting_risk**).

Output variables

Outputs produced by the Firebrand Spotting Parameterization are 2-D and on the atmospheric grid mesh, unless otherwise specified.

- Products (outputs)
    - **fs_count_landed_all**: accumulated firebrand landings during the simulation period
    - **fs_count_landed_hist**: firebrand landings on unburnt gridpoints in the interval between history outputs (history_interval in time_control namelist, not available for auxiliary output streams)
    - **fs_frac_landed**: fraction of fs_count_landed_hist with respect to the total in the corresponding period and domain
    - **fs_spotting_lkhd**: fs_frac_landed scaled by fuel_spotting_risk

Additional outputs relevant for debugging and code development

- **fs_gen_inst**: firebrands generated during the latest generation cycle
- **fs_landing_mask**: logical mask of landings on unburnt gridpoints (latest timestep)

- **fuel_spotting_risk**: 1.0 - MIN(1.0, FuelMoistureContent / FuelMassAtSurface)
- **fs_fire_area**: fire area on the atmospheric grid mesh

Input parameters: processes and categories

Process	Category	Parameter
Firebrand Generation	Frequency	fs_firebrand_gen_dt
	Source Limit	fs_array_maxsize fs_firebrand_gen_lim
	Levels	fs_firebrand_gen_levels fs_firebrand_gen_maxhgt fs_firebrand_gen_levrand
	Momentum	fs_firebrand_gen_mom3d_dt
	Initial Firebrand Properties	fs_firebrand_gen_prop_diam fs_firebrand_gen_prop_effd fs_firebrand_gen_prop_temp fs_firebrand_gen_prop_tvel
Firebrand Physics	Constant Firebrand Properties	fs_firebrand_dens fs_firebrand_dens_char
Firebrand Landing	Thresholds	fs_firebrand_land_hgt fs_firebrand_max_life_dt

Namelist parameters

Variable Names	Input Option	Description
fs_firebrand_gen_dt	5	Sets the frequency to generate new firebrands as a multiple of the inner nest timestep. For example, fs_firebrand_gen_dt = 2 generates a new array of firebrands every other timestep. This parameter does not modify the integration period of other processes, such as transport and firebrand physics.
fs_array_maxsize	100,000	Sets the maximum size of the array storing properties

		of active firebrands. If compiled with MPI support, it corresponds to the array size for each tile. At each generation cycle, elements storing firebrand properties are introduced in this array, while at each timestep, elements corresponding to firebrands that landed, burned out, or exited the domain are removed from the array. If the number of elements available in a tile is lower than the number of firebrand sources for the same tile, new firebrands are not appended to the array for that given tile until enough elements become available in the array. Firebrand sources are the coordinates from where firebrands will be released in each generation cycle. Firebrand sources are unique sets associated with the grid center point on the fire refined grid mesh.
fs_firebrand_gen_lim	0	When set to 0, the scheme is off. Sets an approximate limit to the number of firebrand sources that will generate firebrands per cycle. Only gridpoints where fire Rate-Of-Spread (ROS, [fractional gridpoint area]) is greater than zero during the interval between generation cycles (grid%burnt_area_dt/dt > 0) are considered. If the number of valid points from all tiles is lower than *fs_firebrand_gen_lim*, all sources will generate firebrands. If not, a rank is created using the fuel mass consumed by the fire between two generation cycles as a measure for firebrand generation potential at each source (grid%fgip [kg/m2] x ROS). *See note below about the approximation used for MPI communications*.
fs_firebrand_gen_levels	5	Sets the number of vertical levels to generate firebrands.
fs_firebrand_gen_maxhgt	50	Maximum height to distribute firebrands. Firebrands are distributed between 1 meter Above Ground Level (AGL) and the specified height [m].
fs_firebrand_gen_levrand	false	If set to true, firebrands are randomly placed, if false, firebrands are equally distributed.
fs_firebrand_gen_mom3d_dt	4	Number of advection cycles to allow firebrands to generate 3-D momentum before the burnout process begins.
fs_firebrand_gen_prop_diam	10	Firebrand initial diameter [mm].
	10	Firebrand initial effective diameter [mm].
	900	Firebrand initial temperature [K].
	0	Firebrand terminal velocity at generation height [m/s].

fs_firebrand_dens	513000	Density of firebrands throughout transport [g/m3].
	299000	Density of char throughout transport [g/m3].
fs_firebrand_land_hgt	0.15	Height threshold for firebrand landing in meters above ground level [m].
fs_firebrand_max_life_dt	600	Maximum lifetime of firebrands [seconds].

Note: The MPI communications of all valid grid points from the tiles to the main processor can be time-consuming for large fires. Hence the *fs_firebrand_gen_lim* threshold for the firebrand generation potential is estimated by communicating only two integers from each tile: the median rank of generation potential and the number of valid sources. The main processor uses a linear regression to estimate a cutoff threshold based on fs_firebrand_gen_lim and the total number of valid sources. Because the distributions of fuel mass consumed are non-Gaussian and can vary substantially among tiles, the limit established by fs_firebrand_gen_lim is a rough approximation and may not yield the expected results depending on the case. Setting *fs_firebrand_gen_lim* = *fs_array_maxsize* may prevent firebrand generation in large fire cases because firebrands are not generated when the number of sources exceeds the elements available in the array. Even though the threshold estimation is not accurate, having no threshold would potentially produce biased results, once tiles with lower ROS and lower fuel mass become the only tiles with enough array space to store firebrands.

5. RAL's Fire page

https://ral.ucar.edu/solutions/products/wrf-fire-wildland-fire-modeling

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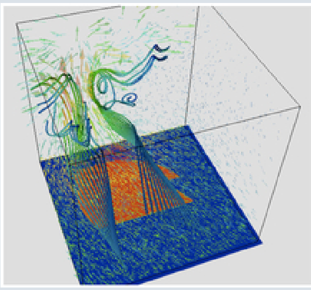
WRF-FIRE FOR WILDLAND FIRE MODELING



Link to Product

WRF-Fire is a physics module within WRF ARW that allows users to model the growth of a wildland fire in response to environmental conditions of terrain slope, fuel characteristics, and atmospheric conditions, and the dynamic feedbacks with the atmosphere. It is implemented as a physics package with two-way coupling between the fire behavior and the atmospheric environment allowing the latent and sensible heat released by the fire to alter the atmosphere surrounding it, i.e. 'create its own weather'. It was first released in Version 3.2 (April 2010).

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The Firebrand Spotting parameterization is an optional module for WRF-Fire released with WRF-ARW v4.4 (April 2022). The parameterization uses a Lagrangian particle transport framework to advect firebrands generated at the fire front and identify areas at risk of fire spotting by modeling transport and physical processes of individual firebrands. The firebrand processes contained in the parameterization are Generation, Transport, Physics, and Landing.

More information on WRF-Fire and the firebrand spotting parameterization can be found on the WRF-ARW User's Guide.
(Include link to user's guide - update address to v4.4)