WRF-Fire

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Introduction

- **WRF-Fire is a physics package within WRF ARW that allows users to model the growth of a wildland fire**
- **Fire responds to environmental conditions:**
  - terrain slope, fuel characteristics, and atmospheric conditions (winds)
- **2-way coupling between the fire behavior and the atmospheric environment**
  - The latent and sensible heat released by the fire alter the atmosphere surrounding it, which in turn affect winds that determine the direction and rate of spread of the fire - i.e. the fire 'creates its own weather'.
- **It was first released in Version 3.2 (April 2010).**
- **Details for use are in *WRF ARW User’s Guide Appendix A***

3 Environmental Factors that affect Wildland Fire Behavior

Fuel

Moisture, mass/area, size, hardwood vs. conifer, spatial continuity, vertical arrangement

Weather

wind, temperature, relative humidity, precipitation
Weather CHANGES: fronts, downslope winds, storm downdrafts, sea/land breezes, diurnal slope winds

Topography

Slope, aspect towards sun, features like narrow canyons, barriers (creeks, roads, rockslides, unburnable fuel)

These are not independent

Coupled Weather – Wildland Fire Modeling

FIRE-WEATHER FEEDBACKS

ATMOSPHERE (Weather model)

Wind, temperature, pressure, density, humidity

The atmosphere (i.e. wind) exerts a force on fires, directing where/how fast they spread and affects fuel properties like fuel moisture that determine whether/how intensely a fire will burn.

Sensible heat flux (temperature) Latent heat flux (water vapor), [smoke]

Wind speed and direction, humidity

Fire Module

Fire rate of spread, Fire intensity

Fires consume fuel and release heat and water vapor into the air, causing it to rise, and changing the winds in the fire's environment.

Example: A fire phenomenon resulting from fire-weather interaction

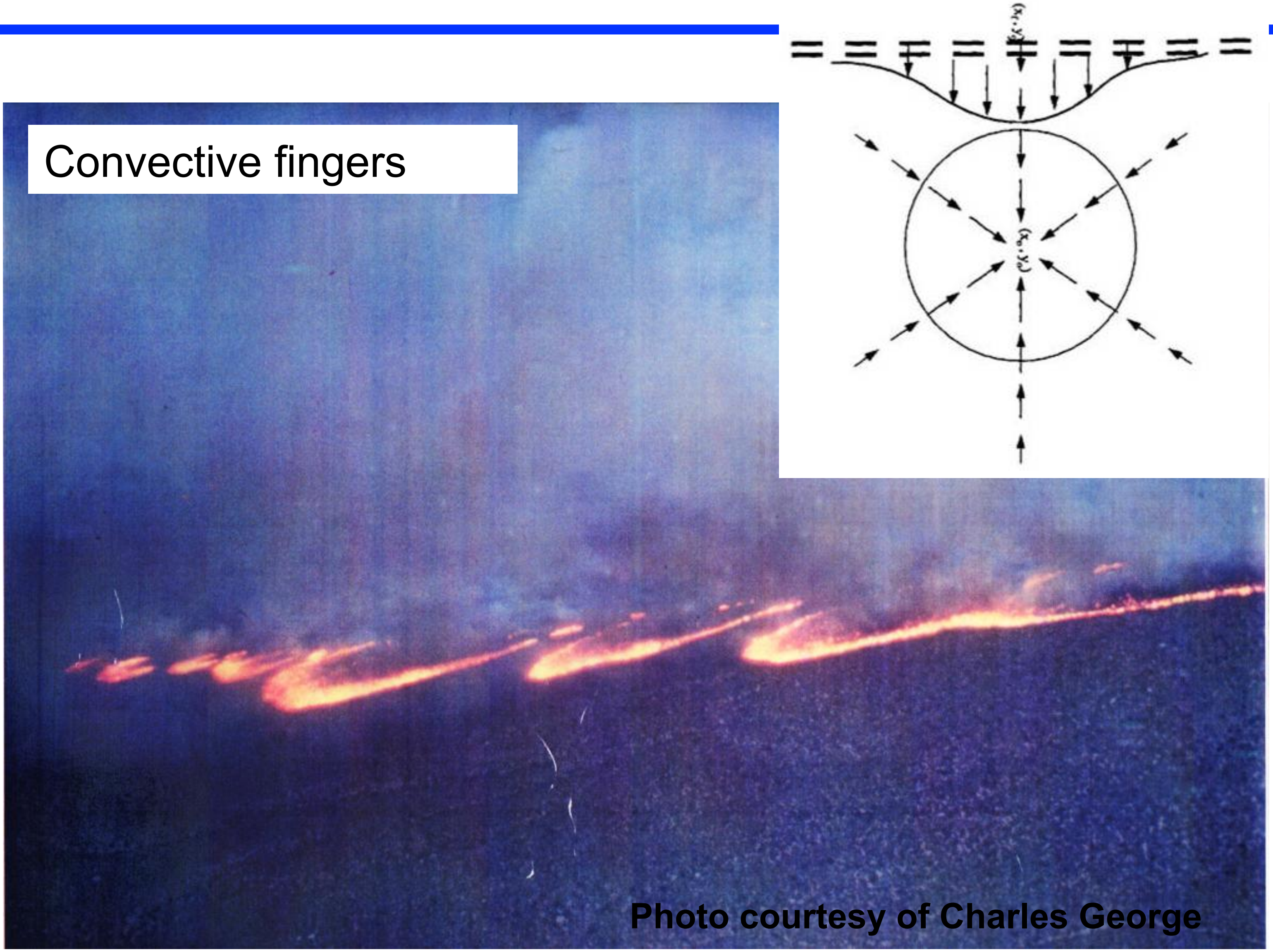
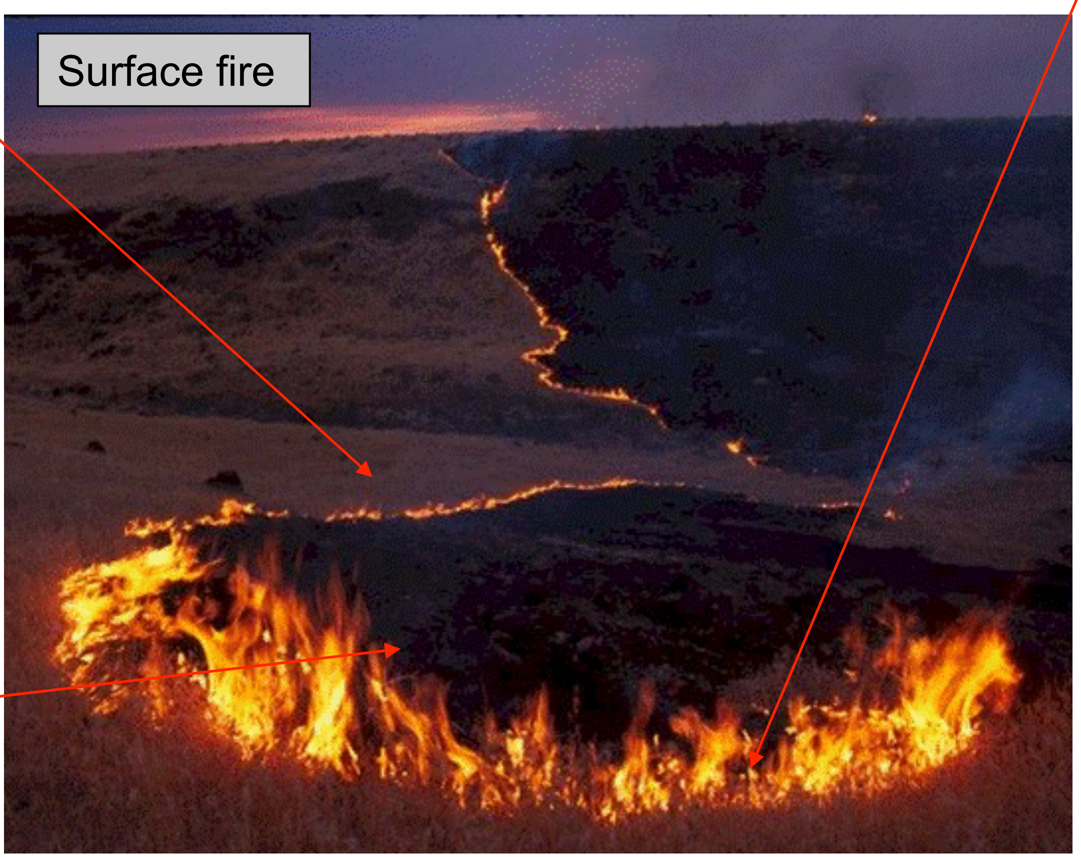


Photo courtesy of Charles George

Physical Processes



Representation of sub-atmospheric grid-scale interface between burning and unignited area

Post-frontal heat & water vapor release

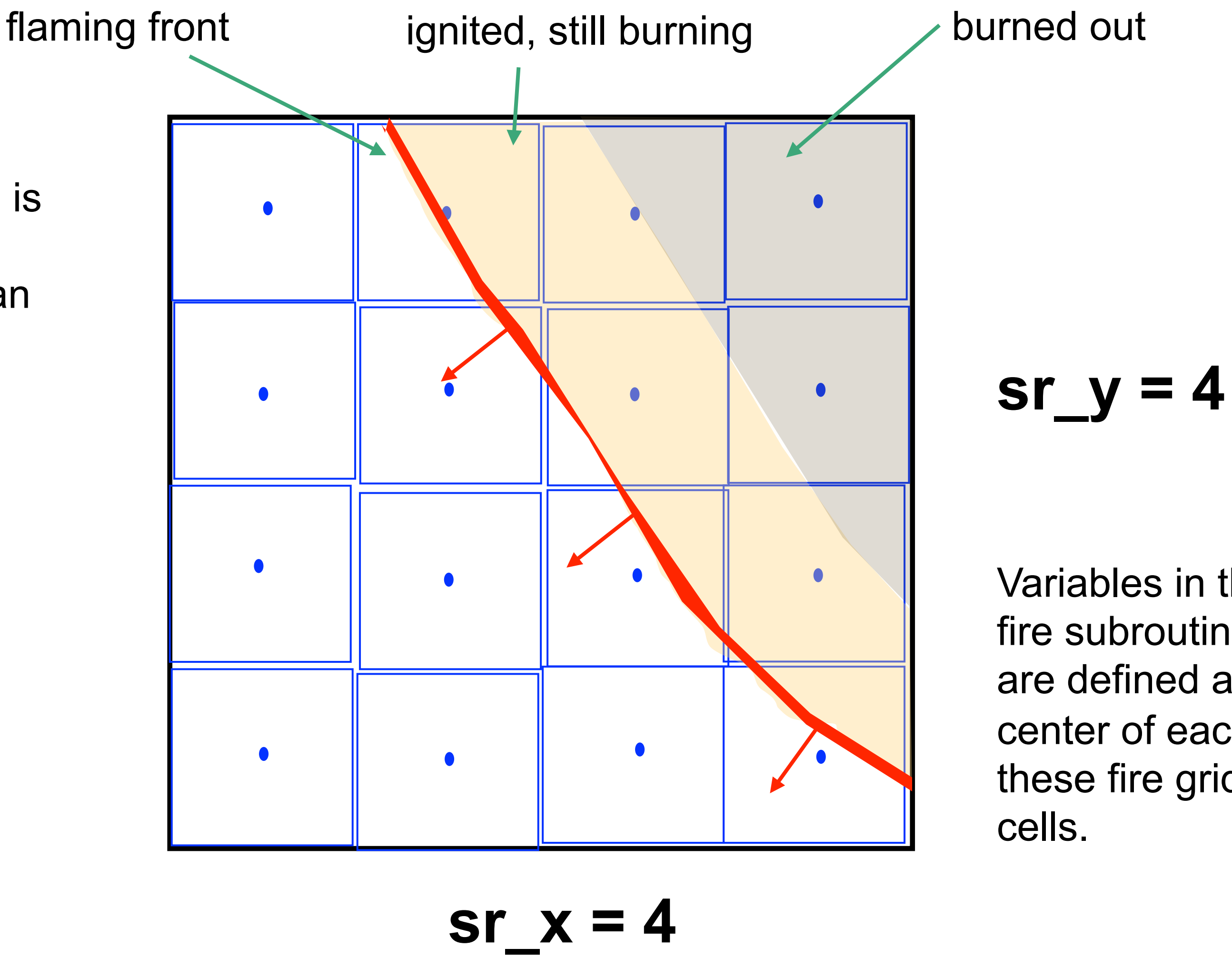
Spread rate of “flaming front” is function of wind, fuel, and slope (Rothermel (1972) semi-empirical equations).

Heat, water vapor, and smoke fluxes released by simulated fire into lowest layers of atmospheric model

What do these subroutines do?

- **User specifies time, location, and shape of a fire ignition**
- **At each atmospheric time step for the innermost grid:**
  - Interpolate the near-surface winds to the fire cell grid points.
  - Calculate the rate at which the interface enclosing the burning region expands at points all along it with a semi-empirical formula (Rothermel, 1972)
  - Advance the fire front for this time step.
  - Calculate how much mass has been burned (integrated over the burning area within each fire cell) and multiply by the energy content of the fuel (J/kg) to get energy release rate (J/(s m^2), or W/m^2).
  - Sum up the heat release for all the fire cells within each atmospheric cells.
    - Sensible heat flux (temperature) - W/m^2
    - Latent heat flux (water vapor) - W/m^2
      - 56% each cellulose cell is water
      - Fuel moisture content is the fuel absorbed between the cells
  - Distribute this as a tendency to the lowest levels of the atmospheric model
- **Return to atmospheric model**

Within each x-y atmospheric grid cell on the earth's surface is a x-y mesh of fire grid cells



The fire mesh is sr_x by sr_y times finer than the innermost atmospheric mesh.

Variables in the fire subroutines are defined at the center of each of these fire grid cells.

Spread Rate of a Flaming Front

(Semi-empirical) Rothermel eqns (1972)

$$R = \underbrace{\frac{I_R \xi}{\rho_b \varepsilon Q_{ig}}}_{\text{Zero-wind spread rate on flat ground}} (1 + \underbrace{\phi_w}_{\text{wind factor}} + \underbrace{\phi_s}_{\text{slope factor}})$$

$$\frac{\text{Heat energy of fuel}}{\text{Heat required to prepare fuel \& ignite}}$$

R_0 = f(fuel characteristics) (i.e. the type, amount, surface area/volume ratio, heat content, particle density, moisture content, depth, mineral content, moisture content of extinction)

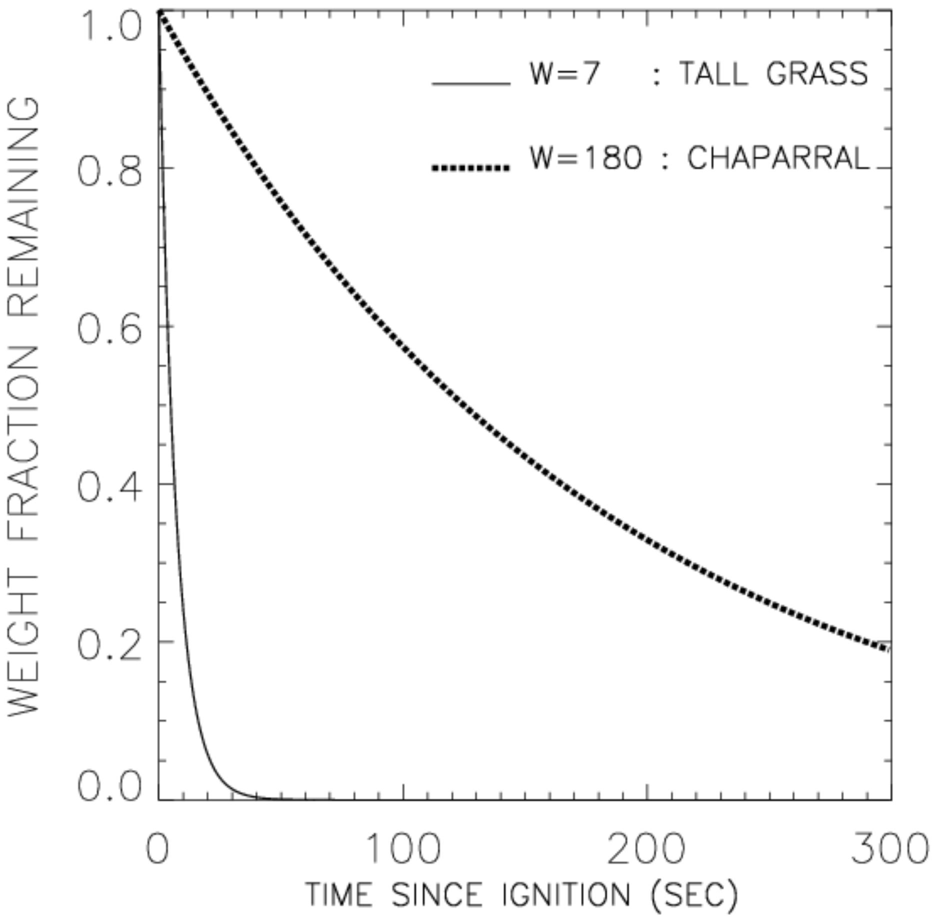
Mass loss rate after ignition

Once fuel ignites, its mass decreases. Lab experiments show that the mass decreases approximately exponentially.

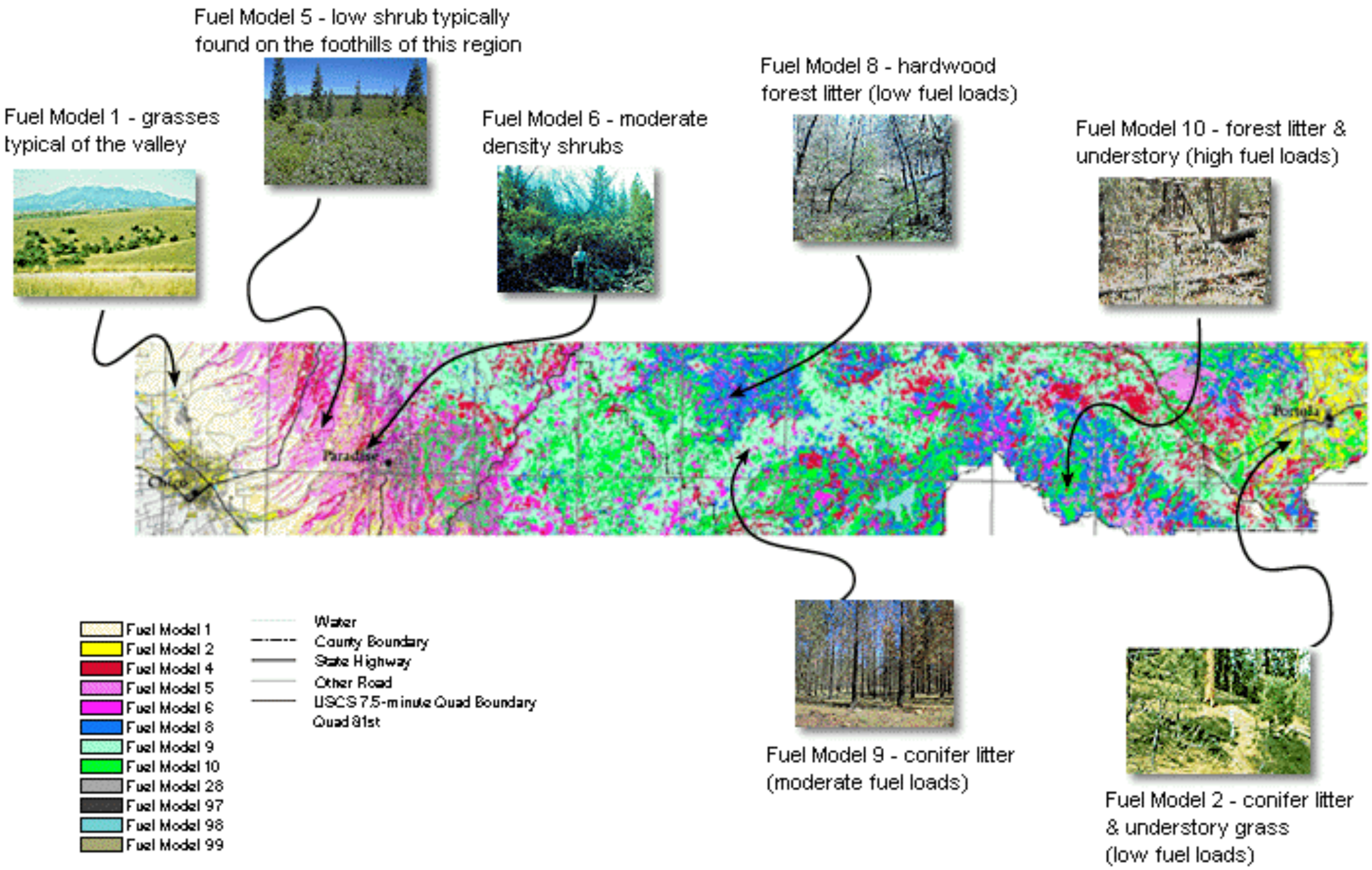
An approximation to the BURNUP (Albini, 1994) algorithm treats the rate of mass loss due to burning for fuel of different types and sizes.

Reference:

Albini FA (1994) PROGRAM BURNUP, A simulation model of the burning of large woody natural fuels. Final Report on Research Grant INT-92754-GR by U.S.F.S. to Montana State Univ., Mechanical Engineering Dept.



A “Fuel Model” is a collection of fuel properties based on the amount, physical properties, and spatial distribution of surface fuel elements



Cross Section of Fuel Map
from Northern Sacramento Valley to Portola

Image courtesy of California Division of Forestry

The most commonly used fuel classification system is the 13-category Anderson fuel model system

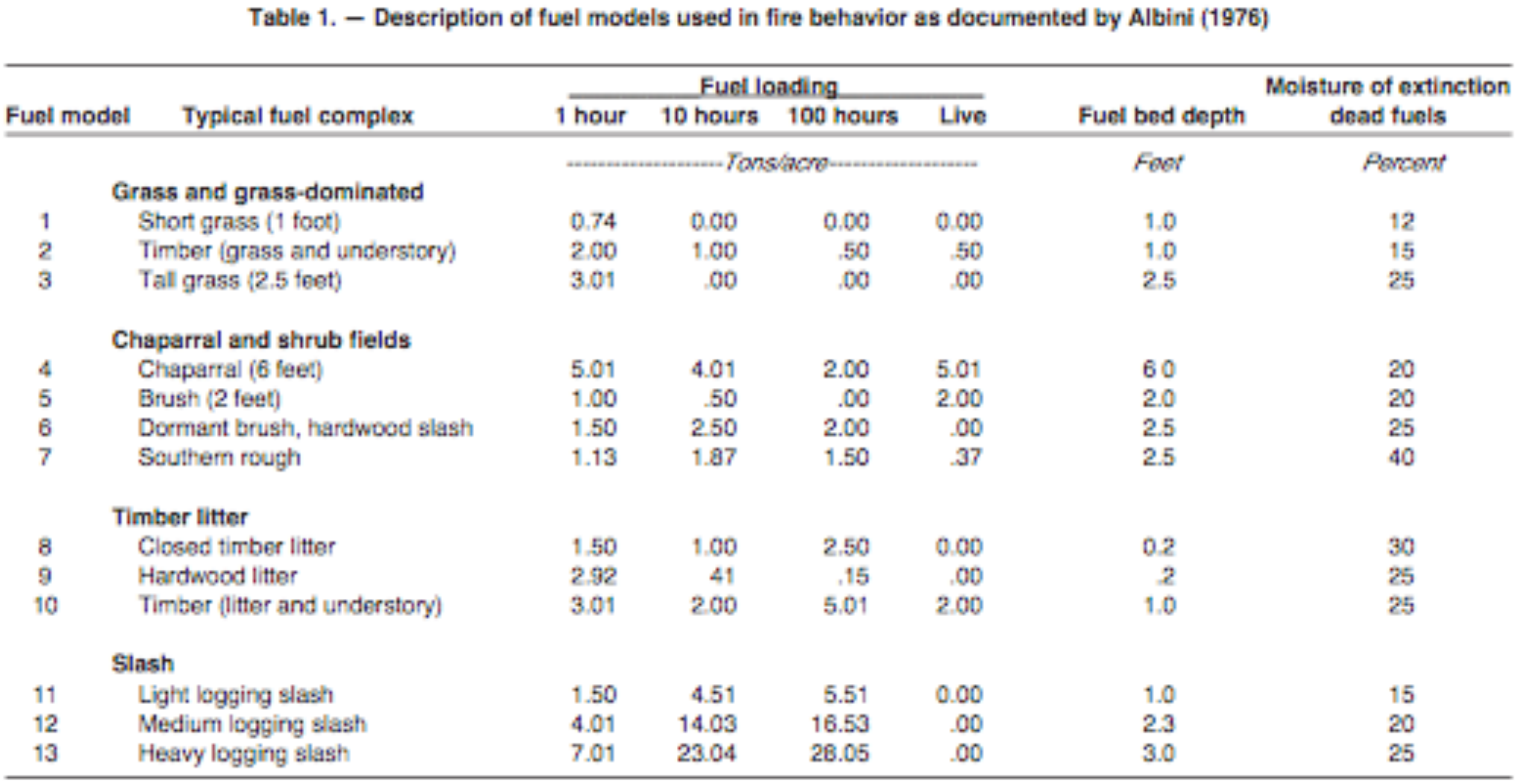


Table 1. — Description of fuel models used in fire behavior as documented by Albini (1976)

Fuel model	Typical fuel complex	Fuel loading				Fuel bed depth	Moisture of extinction dead fuels
		1 hour	10 hours	100 hours	Live		
		------------*Tons/acre*------------				*Feet*	*Percent*
	Grass and grass-dominated						
1	Short grass (1 foot)	0.74	0.00	0.00	0.00	1.0	12
2	Timber (grass and understory)	2.00	1.00	.50	.50	1.0	15
3	Tall grass (2.5 feet)	3.01	.00	.00	.00	2.5	25
	Chaparral and shrub fields						
4	Chaparral (6 feet)	5.01	4.01	2.00	5.01	6 0	20
5	Brush (2 feet)	1.00	.50	.00	2.00	2.0	20
6	Dormant brush, hardwood slash	1.50	2.50	2.00	.00	2.5	25
7	Southern rough	1.13	1.87	1.50	.37	2.5	40
	Timber litter						
8	Closed timber litter	1.50	1.00	2.50	0.00	0.2	30
9	Hardwood litter	2.92	41	.15	.00	.2	25
10	Timber (litter and understory)	3.01	2.00	5.01	2.00	1.0	25
	Slash						
11	Light logging slash	1.50	4.51	5.51	0.00	1.0	15
12	Medium logging slash	4.01	14.03	16.53	.00	2.3	20
13	Heavy logging slash	7.01	23.04	28.05	.00	3.0	25

Anderson, H. E. 1982. *Aids to determining fuel models for estimating fire behavior.* USDA For. Serv. Gen. Tech. Rep. INT-122, 22p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401) at **http://www.fs.fed.us/rm/pubs_int/int_gtr122.pdf**

Idealized Cases

- **To perform a WRF simulation including the ignition and growth of a wildland fire**
  - Change to test directory, test/em_fire
  - Configure your user environment and configure WRF in the usual way
  - Compile the test case:
    - `./compile em_fire`
  - Copy these files from one of the example directories:
    - the usual input files (`namelist.input` and `input_sounding`)
    - the additional namelist, `namelist.fire` .
  - Configure these for your case
    - Note: `namelist.input` contains an additional section `&fire` with fire model parameters and ignition parameters
    - `namelist.input` contains an additional namelist to enter custom fuel properties
  - `./ideal.exe`
  - `./wrf.exe`

`namelist.input` section `&domains`

Variable names	Value	Description
`&domains`		Domain definition
`sr_x`	10	The fire mesh is 10 times finer than the innermost atmospheric mesh in the *x* direction. This number must be even.
`sr_y`	10	The fire mesh is 10 times finer than the innermost atmospheric mesh in the *y* direction. This number must be even.

`namelist.input` section `&fire`

Variable names	Value	Description
`&fire`		Fire ignition and fuel parameters
`ifire`	0	No fires will be simulated.
	1	Fires will be simulated, using the tracer scheme to represent the flaming front interface (not active).
	2	Fires will be simulated, using the level set method to represent the movement of the interface.
`fire_fuel_read`	0	How to set the fuel data -1: real data from WPS
		0: set to a homogeneous distribution of `fire_fuel_cat` everywhere
		1: The spatial distribution of fuel categories is to be specified as a function of terrain altitude. (The user specifies a custom function.)

`namelist.input` section `&fire`

Variable names	Value	Description
`fire_num_ignitions`	3	Number of ignition lines, max. 5 allowed
`fire_ignition_start_x1`	1000.	*x* coordinate of the start point of the ignition line 1. All ignition coordinates are given in m from the lower left corner of the innermost domain
`fire_ignition_start_y1`	500.	*x* coordinate of the start point of the ignition line 1
`fire_ignition_end_x1`	1000.	*y* coordinate of the end point of the ignition line 1. Point ignition (actually a small circle) is obtained by specifying the end point the same as the start point.
`fire_ignition_end_y1`	1900.	*y* coordinate of the end point of the ignition line 1
`fire_ignition_radius1`	18.	Everything within `fire_ignition_radius1` meters from the ignition location will be ignited.
`fire_ignition_time1`	2.	Time of ignition in s since the start of the run
`fire_print_msg`	1	0: no messages from the fire scheme 1: progress messages from the fire scheme

`namelist.fire`

Variable names	Description
`&fuel_scalars`	Scalar fuel constants
`cmbcnst`	The energy released per unit fuel burned for cellulosic fuels (constant, 1.7433e7 J kg^{-1}).
`hfgl`	The threshold heat flux from a surface fire at which point a canopy fire is ignited above (in W m^{-2}).
`fuelmc_g`	Surface fuel, fuel moisture content (in percent expressed in decimal form, from 0.00 – 1.00).
`fuelmc_c`	Canopy fuel, fuel moisture content (in percent expressed in decimal form, from 0.00 – 1.00). (not active).
`nfuelcats`	Number of fuel categories defined (default: 13)
`no_fuel_cat`	The number of the dummy fuel category specified to be used where there is 'no fuel'

`namelist.fire`

Variable names	Description
`&fuel_categories`	Domain specifications
`fgi`	The initial mass loading of surface fuel (in kg m^{-2}) in each fuel category
`fueldepthm`	Fuel depth (m)
`savr`	Fuel surface-area-to-volume-ratio (m^{-1})
`fuelmce`	Fuel moisture content of extinction (in percent expressed in decimal form, from 0.00 – 1.00).
`fueldens`	Fuel particle density lb ft^{-3} (32 if solid, 19 if rotten)
`st`	Fuel particle total mineral content. (kg minerals/kg wood)
`se`	Fuel particle effective mineral content. (kg minerals – kg silica)/ kg wood

`namelist.fire`

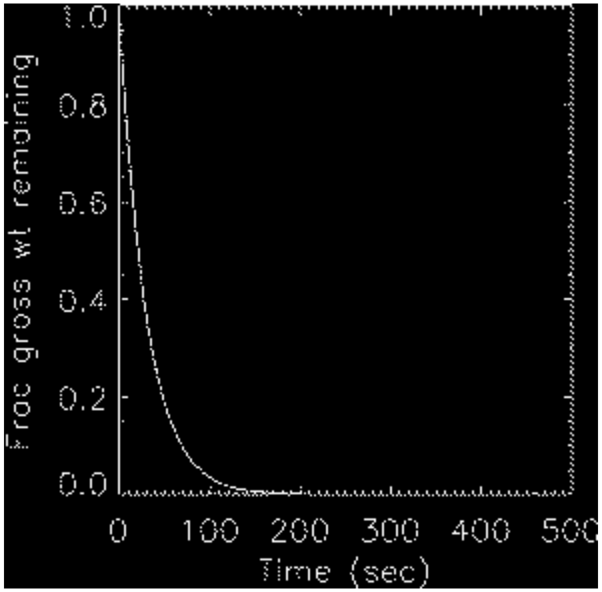
Variable names	Description
`weight`	Weighting parameter that determines the slope of the mass loss curve. This can range from about 5 (fast burn up) to 1000 (40% decrease in mass over 10 minutes).
`fci_d`	Initial dry mass loading of canopy fuel (in kg m^{-2}) (Not used.)
`fct`	The burnout time of canopy fuel once ignited (s) (Not used.)
`ichap`	Is this a chaparral category to be treated differently using an empirical rate of spread relationship that depends only on wind speed? (1: yes, this is a chaparral category and should be treated differently; 0: no, this is not a chaparral category or should not be treated differently). Primarily used for Fuel Category 4.

Fraction of fuel remaining with time

“Flashy” fuels

Grass

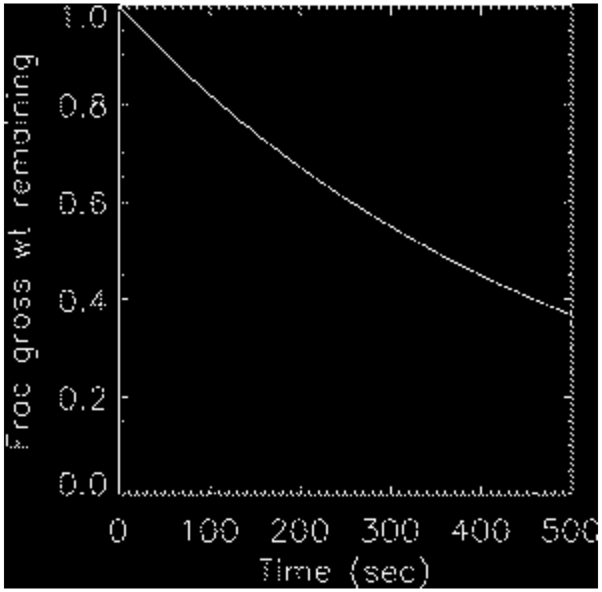
W=30 s



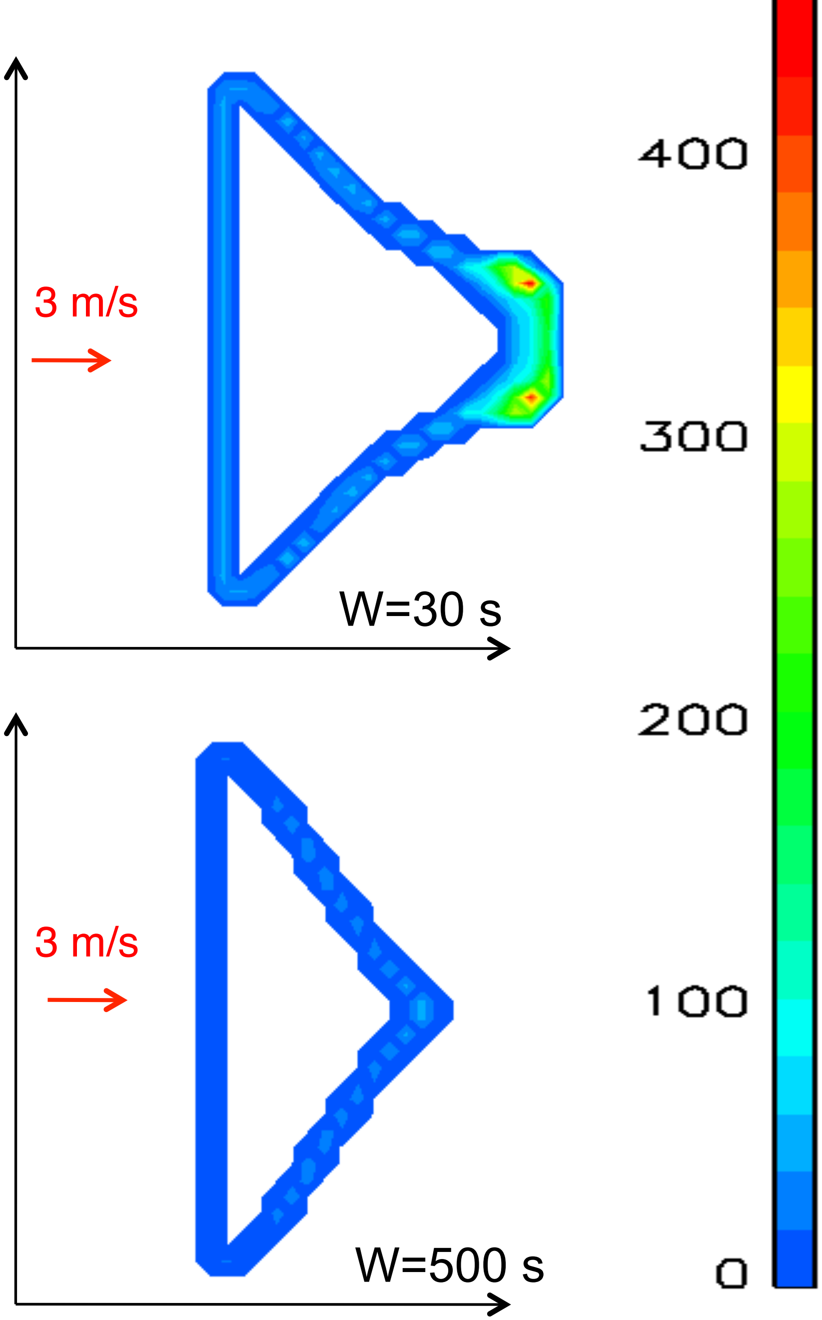
Slow-burning

Woody fuel mixture

W=500 s



Heat flux(kW/m^2)



Additional Variables in wrfout* for Analysis

These variables are located at the center of the fire grid cells.

`LFN`	level set function. Node (i,j) is on fire if LFN(i,j)<=0
`FXLONG, FXLAT`	longitude and latitude of the nodes
`FGRNHFX`	ground heat flux from the fire (W/m^2), averaged over the cell
`FGRNQFX`	ground heat flux from the fire (W/m^2), averaged over the cell
`ZSF`	terrain elevation above sea level (m)
`UF,VF`	surface wind

`FIRE_AREA`	approximate part of the area of the cell that is on fire, between 0 and 1

Real Case

To perform a WRF simulation in a 'real' case: Requires user's involvement. Not completely automated.

- **Configure your user environment and configure WRF in usual way before WPS**
- **Compile the real case:**
  - `./compile em_real`
- **WPS**
  - Configure and compile WPS from the ./WPS directory:
    - `./configure`
    - `./compile`
  - Ungrib and metgrid used the same way. Additional datasets and variables for geogrid:
    - `NFUEL_CAT` - Spatial map of fuel categories. User supplies data.
    - `ZSF` – high resolution terrain. User supplies data.
    - `Add NFUEL_CAT and ZSF to` in `GEOGRID.TBL`

Real Case

- Configure namelist.wps with an additional parameter:

Variable	Description
`Subgrid_ratio_[xy]`	The refinement ratio from the atmospheric grid to the fire grid.

- Run WPS components (./geogrid.exe, ./ungrib.exe, ./metgrid.exe)

- **WRF**
  - As in ideal experiment, include the extra fire variables in `namelist.input` and `namelist.fire`
  - `./real.exe`
  - `./wrf.exe`

Caveats

- **Not currently for use for crown fires in forests**
  - In a forest, this model represents the creeping spread of fire on the ground below the branches.
- **How successful the simulation is depends, among other things, on how well you model low-level winds**
- **Most experiments so far run in LES mode, small time steps**
  - Not presented as a real-time application
- **Data for real experiment**
  - Interpolation to < 100 m-scale grid with high-resolution GIS data is not quite there yet.
- **Even though things can be done, may not always be a good idea to do it:**
  - Not all scales make sense. Still figuring out what those are.
  - Fuel datasets - physical values, especially of fuel loads (mass/area), should be used with extreme caution.


Crown fire

Thank you!

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