Updates to biomass to charcoal conversions and modifications to charcoal dispersion

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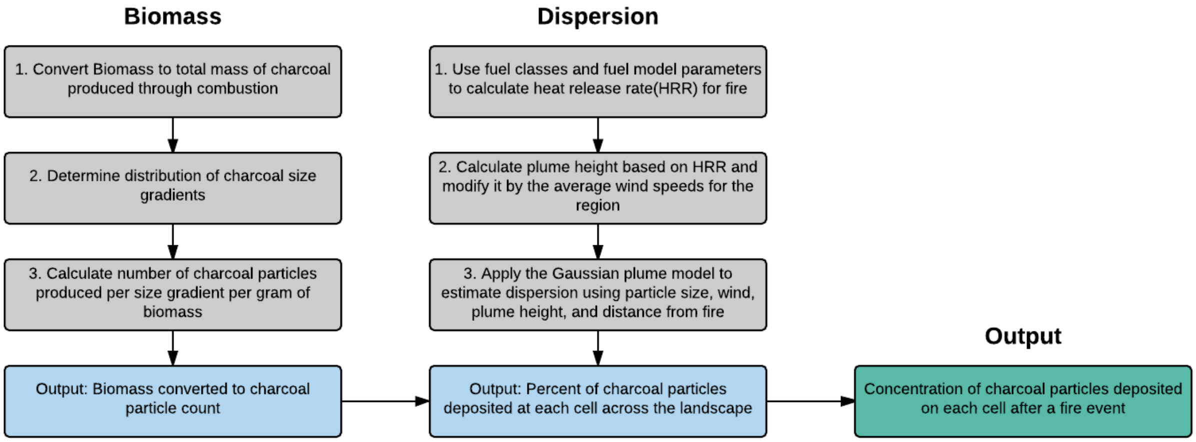
New additions

- Incorporating long-established fuel models (Anderson 1982) that classify vegetation communities by their flammability, potential for fire rate of spread, and biomass. Aids in connecting this work to language and standards used in fire ecology.
- Adding heat release rate (HHR) to estimate the height of a convective plume based on the fuel model that is being combusted.
- Incorporated fuel class (not to be confused with fuel models). Fuel class specifies the potential intensity of a fire based on the burnability time lag of fuels available to it. Depends on fuel diameter, moisture content, dead/alive status, etc. 1hr fuels are small diameter, easily burnable fuels with limited potential intensity. 100hr fuels are larger diameter fuels that take longer to ignite and burn, but have the potential for greater intensities.

Overall Calculations Flowchart



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Biomass

1. Estimates of biomass converted to charcoal in fire (updated from 2% (Gavin 2001) to values summarized in Forbes et al. 2006).

Coded Value	MEDLAND Veg. Type	Fuel Model	Taxa	% Biomass consumed in Fire	% of Consumed Biomass Converted to Charcoal	% Biomass Converted to Charcoal
5	grassland	1	Brachypodium retusum	99.30	0.49	0.48
19	maquis	4	Ulex parviflorus, Cistus albidus, Rosmarinus officinalis	91.20	1.11	1.01
32	mostly young open woodland and very sparse maquis	6	Pinus, Quercus, Ulex parviflorus, Cistus albidus, Rosmarinus officinalis	55.00	5.90	3.25

2. Distribution of charcoal size gradients from experimental fires (Pitkanen et al. 1999):

Size Gradient (µm)	% Charcoal at 20m from burn	% Charcoal at 50m from burn	% Charcoal at 100m from burn	Avg % of total charcoal
<50	46.00	46.00	47.00	46.33
50-200	26.00	31.00	35.00	30.67
200-400	7.00	2.00	7.00	5.33
400-600	4.00	3.00	1.00	2.67
>600	17.00	18.00	10.00	15.00
total	100.00	100.00	100.00	

3. Calculate charcoal particle count per size gradient from biomass (Clark 1998):

Hypothetical biomass converted to charcoal (g) per cm3	Avg % Charcoal (0-1)	Simplified size gradient (µm); >600 not included	Mass of charcoal by size gradient (g)	Avg. Density of Charcoal g/cm^3	**Continued below ->**
1	0.4633	50	0.4633	0.5	
	0.3067	200	0.3067	0.5	
	0.0533	400	0.0533	0.5	
	0.0267	600	0.0267	0.5	

Volume of charcoal cm3 (derived from mass and density)	Calculate volume of charcoal particles: Vol (µm^3)= 4/3πr^3	Convert µm^3 to cm^3	Convert total volume of charcoal to pieces per cm3
0.9266	65416.66667	6.54167E-08	14164585.99
0.6134	4186666.667	4.18667E-06	146512.74
0.1066	33493333.33	3.34933E-05	3182.73
0.0534	113040000	0.00011304	472.40

Dispersion

1. Biomass to HHR

The heat release rate of flames is used to determine how high a convective smoke plume will rise during a fire. The height of a plume, along with other factors, determines how far charcoal particles will travel during aerial dispersion. The formula used here comes from fire behavior research conducted by the US Forest Service in the 1970's in an effort to help firefighters and managers plan for smoke and ash fallout from large forest fires. The equation is as follows:

$$\mathrm{HRR} = 0.0012\, y_A\, wrL \qquad (1)$$

where HRR = heat release rate to the atmosphere in megacalories per second

y_A = fractional part of available fuel involved in the advancing-front combustion stage (range 0.01 to 1.00)

w = weight of available fuel in tons per acre

r = rate of spread in feet per minute

L = length of fire front in feet.

This equation connects fuel model parameters, such as biomass and fuel classifications, to the size of a plume that will be generated from combustion. More information can be found in Mobley 1976. The calculations of plume height used for fuel models in Valencia region can be found in this worksheet.

2. Plume height modified by wind velocity

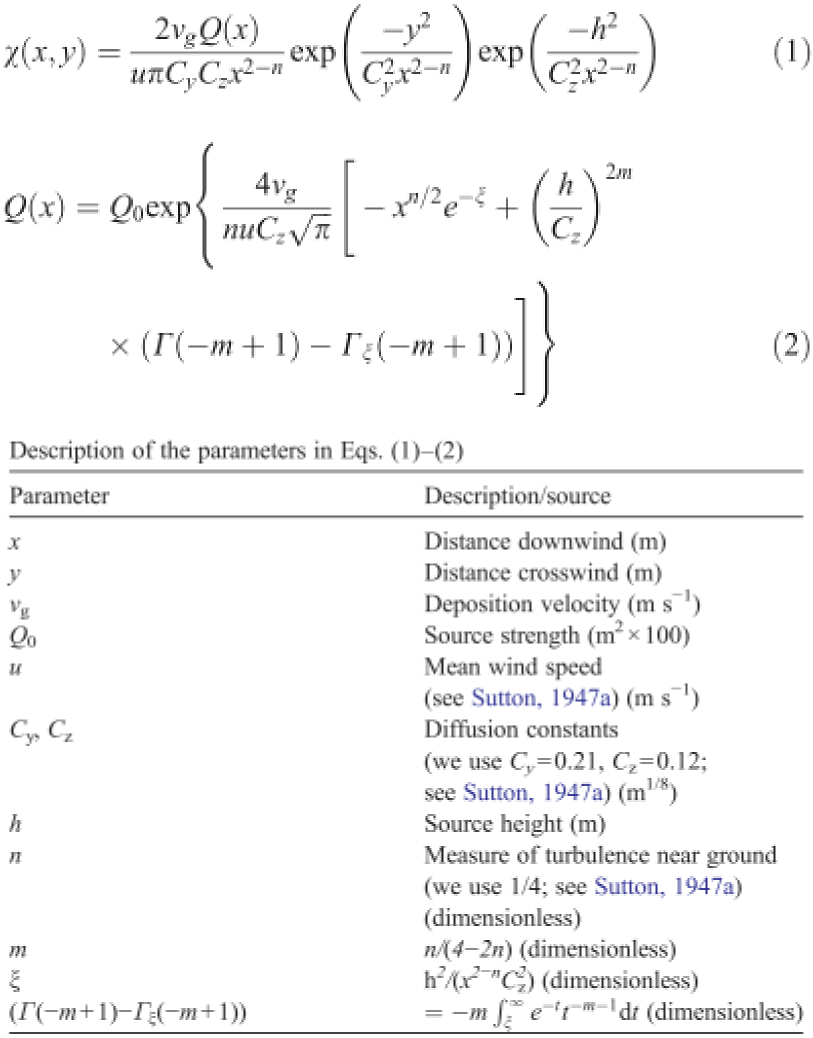
Plume heights are also modified by average wind velocity during combustion and convective uplift. To accommodate for this effect, the following formula is applied to the HRR value for each fuel model or vegetation type. In H(q,u), q is the mean total heat release rate (cal sec^{-1}), and u is the average wind speed (m sec^{-1}):

$$H(q,\mathrm{u}) = \begin{cases} 0.01q^{\,0.75}/\mathrm{u}, & q < 1.4 \times 10^6, \\ 0.085q^{\,0.6}/\mathrm{u}, & q > 1.4 \times 10^6, \end{cases} \qquad (5)$$

Wind modifications to the plume can again be found in this worksheet. Additional information about this equation and its implications can be found in Clark 1988.

3. Gaussian Plume Model

Gaussian plume modeling was first developed to examine fallout from atomic weapons, but was adapted for modeling charcoal dispersion in the 1980's (Clark 1988). Clark's application of the Gaussian plume model has been empirically verified and applied elsewhere to charcoal collected from lake cores. The following is the plume model and inputs as described in Peters and Higuera 2007:



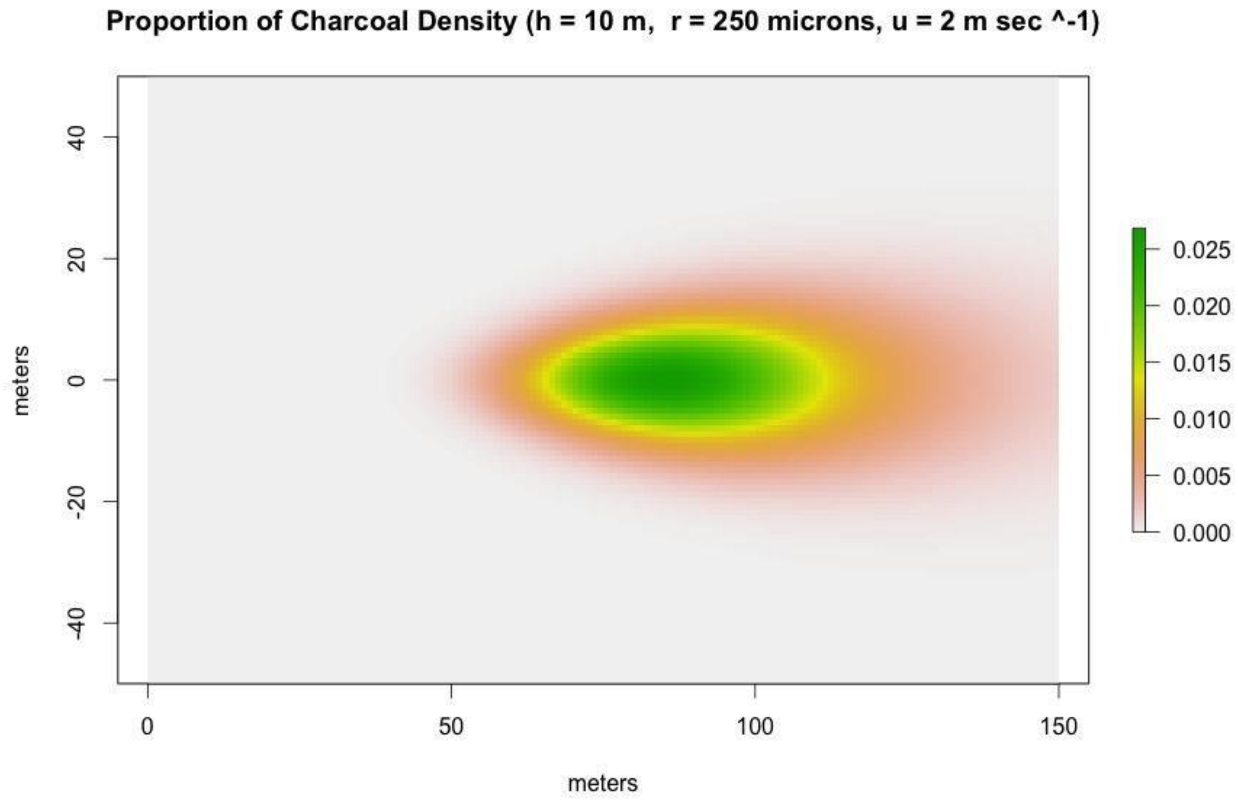
$$\chi(x,y) = \frac{2v_g Q(x)}{u\pi C_y C_z x^{2-n}} \exp\left(\frac{-y^2}{C_y^2 x^{2-n}}\right) \exp\left(\frac{-h^2}{C_z^2 x^{2-n}}\right) \qquad (1)$$

$$Q(x) = Q_0 \exp\left\{ \frac{4v_g}{nuC_z\sqrt{\pi}} \left[-x^{n/2}e^{-\xi} + \left(\frac{h}{C_z}\right)^{2m} \times \left(\Gamma(-m+1) - \Gamma_\xi(-m+1)\right) \right] \right\} \qquad (2)$$

Description of the parameters in Eqs. (1)–(2)

Parameter	Description/source
x	Distance downwind (m)
y	Distance crosswind (m)
v_g	Deposition velocity (m s^{-1})
Q_0	Source strength ($m^2 \times 100$)
u	Mean wind speed (see Sutton, 1947a) (m s^{-1})
C_y, C_z	Diffusion constants (we use C_y=0.21, C_z=0.12; see Sutton, 1947a) ($m^{1/8}$)
h	Source height (m)
n	Measure of turbulence near ground (we use 1/4; see Sutton, 1947a) (dimensionless)
m	$n/(4-2n)$ (dimensionless)
ξ	$h^2/(x^{2-n}C_z^2)$ (dimensionless)
$(\Gamma(-m+1)-\Gamma_\xi(-m+1))$	$= -m\int_\xi^\infty e^{-t}t^{-m-1}dt$ (dimensionless)

This version of the model is 2-D and adapted to estimate the concentration of charcoal particles at a given point on the landscape after fallout. Relevant variables include x and y distances from the fire, wind velocity, plume height, and particle diameter. The following is an example of the 2-D output:



An R script for applying this Gaussian plume model can be found here.

Output

Now, simply multiply the proportion of the charcoal that should be dispersed to a given cell after a fire event by the total number of charcoal particles created through the combustion of the original biomass. The result will be the concentration of charcoal particles per size of the cell they are deposited on.

References

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