Rothermel vs. Balbi rate of spread model

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Outline

- Overview of Rothermel model
- Initial Rothermel ROS equation
- Evaluating Each Component
- Final Rothermel ROS equation
- Overview of the Balbi model
- Evaluating Each Component
- Comparisons between the models
- References
- Questions
- Thank you

Rothermel Model

- The original Rothermel model was created by Richard C. Rothermel in 1972 and was based on a heat balance model developed by Fransden in 1971
- The goal of this model was to calculate the rate of spread of a fire in various conditions quickly and accurately
- This is a semi-empirical model, meaning the model was formulated using some physical properties and observational/statistical data

- The authors initially created the model assuming no wind/slope conditions to make formulating the model easier
- The slope and wind parameters were added in later after the initial model was created
- Assumptions and simplifications are necessary to reduce Equation 1 down to a more manageable calculation

Initial Rothermel rate of spread equation

$$R = \frac{I_{xig} + \int_{-\infty}^{0} (\frac{\partial I_z}{\partial z})_{z_c} \, dx}{\rho_{be} * Q_{i_g}} \qquad (1)$$

- R = Quasi-steady rate of spread, ft./min.
- I_{xig} = horizontal heat flux absorbed by a unit volume of fuel at the time of ignition, $B.t.u/ft.^2$ -min
- ρ_{be} = Effective bulk density, lb./ft.3
- Q_{ig} = heat of preignition,. B.T.U./lb
- $(\frac{\partial I_z}{\partial z})_{z_c}$ = The gradient of the vertical intensity evaluated at a plane at a constant depth, z_c, of the fuel bed, B.t.u./ft.^{3} -min

Evaluating Each Component

Every component for the Rothermel model

$$Q_{ig} = C_{pd}\Delta T + M_f(C_{pw}\Delta T_B + V) \tag{2}$$

$$Q_{ig} = 250 + 1116 * M_f.B.T.U/lb. \tag{3}$$

$$I_R = -(\frac{\mathrm{d}w}{\mathrm{d}x})(\frac{\mathrm{d}x}{\mathrm{d}t})h \tag{4}$$

$$I_R D = R * h(W_n - W_r) \tag{5}$$

$$\Gamma = \Gamma' \eta_M \eta_s \tag{6}$$

$$\beta = \frac{\rho_b}{\rho_p} \tag{7}$$

$$\sigma = \frac{4}{d} \tag{8}$$

Evaluating Each Component

Every component for the Rothermel model

$$\Gamma' = \frac{\Gamma}{\eta_M \eta_S} \tag{9}$$

$$\Gamma' = \Gamma'_{max} (\frac{\beta}{\beta_{op}})^A exp[A(1 - \frac{\beta}{\beta_{op}})] \tag{10}$$

$$(I_P)_o = R_0 \rho_b \epsilon Q_{ig} \tag{11}$$

$$\phi_W = C U^B (\frac{\beta}{\beta_{op}})^{-E} \tag{12}$$

$$\phi_S = 5.275 \beta^{-.3} (tan\phi)^2 \tag{13}$$

Final ROS Equation

$$R = \frac{I_R \zeta (1 + \phi_W + \phi_S)}{\rho_b \epsilon Q_{ig}} \tag{14}$$

Balbi Model

Overview of the Balbi Model

Different versions of the Balbi Model

- There are multiple versions of the Balbi model
- The first model being created in 2007 and the last revision made this year (2022)
- Improvements have been made to the model over time to make it more accurate by accounting for more physical properties within a fire
- The goal of this model is to provide an accurate ROS calculation faster than real time

Overview of the Balbi Model

Physical model

- The Balbi model is a fully physics based model
- There are no observations/statistical data used to build the model, only physical processes occurring within a fire
- Like with Rothermel, the initial model was designed without slope and wind in mind to simplify formulating the model
- Slope and wind was then added in later since it is a necessary component to fire spread

Evaluating Each Equation

Every component for the base model

$$\tan \beta_w = \frac{\nu_w}{u_{fl}} \tag{15}$$

$$\gamma = \alpha + \beta_s \tag{16}$$

$$\tan \beta_s = \frac{\nu_s}{u_{fl}} \tag{17}$$

$$H = H^* Q^{\frac{2}{5}} = H^* (\Delta h_{fu} \sigma_{fu} c)^{\frac{2}{5}} \tag{18}$$

$$\rho_g \frac{\partial u}{\partial t} = (\rho_a - \rho_g) g \tag{19}$$

Evaluating Each Equation

Every component for the Balbi model

$$u_{fl} = Q^{\frac{1}{5}} \sqrt{(\frac{T_{fl}}{T_a} - 1) g H^*} \tag{20}$$

$$\rho_g u_{fl} l = \rho_{ga} h \nu_u + D \dot{\sigma}_{fu} \tag{21}$$

$$\rho_a h \nu_u = \upsilon D \dot{\sigma}_{fu} \tag{22}$$

$$T_{fl} = T_a + \frac{(1-\chi) Q}{(\upsilon + 1) D \dot{\sigma}_{fu} c_{pg}} = T_a + \frac{1-\chi) \Delta h_{fu}}{(\upsilon + 1) c_{pg}} \tag{23}$$

$$R_b = \sigma T_{fl}^4 \mathrm{d}(\delta - x) \tag{24}$$

Evaluating Each Equation

Every component for the Balbi model

$$R_{fl} = \epsilon_{fl}\sigma \frac{T_{fl}^4}{2}(1 - \cos\theta) \tag{25}$$

$$\sigma_{fu} c_{pfu} \frac{\mathrm{d}T_{fu}}{\mathrm{d}t} = R_b + R_{fl} - \Delta h_w \frac{\mathrm{d}\sigma_w}{\mathrm{d}t} \tag{26}$$

$$c_1 = \frac{\sigma T_{fl}^4 \mathrm{d}\delta^2}{2\sigma_{fu}(c_{pfu}(T_{ig} - T_a) + \Delta h_w \eta)} \tag{27}$$

$$c_h = c_l + \frac{\epsilon_{fl}\sigma T_{fl}^4 H}{2\sigma_{fu}(c_{pfu}(T_{ig} - T_a) + \Delta h_w \eta)}(1 + \sin\gamma - \cos\gamma) \tag{28}$$

Evaluating Each Equation

Every component for the Balbi model

$$\varepsilon_{fl}\sigma T_{fl}^4 = \chi Q/H \tag{29}$$

$$\phi_c = \frac{\Delta H}{2\tau_0}\sigma smin(h,\delta)\tan\gamma_c \tag{30}$$

$$\tan\gamma_c = \tan\alpha + \frac{U(L)}{u_c} \tag{31}$$

$$\begin{aligned} R_c = a_M min(\frac{W_0}{50},1) * \frac{\Delta H \rho_a T_a s\sqrt{h}}{2q(s_t+1)\rho_v T}(\frac{(s_t+1)\rho_v T}{\tau_0 \rho_a T_a} * \\ min(S, \frac{2\pi S}{S_t}\tan\alpha + U\exp(-\frac{\beta_t}{min(\frac{W_0}{50},1)}R)) \end{aligned} \tag{32}$$

Final Balbi ROS Equation

$$R = R_c + R_b + R_f \tag{33}$$

Comparing the Models

Comparisons between the models

Wind Speed Comparison

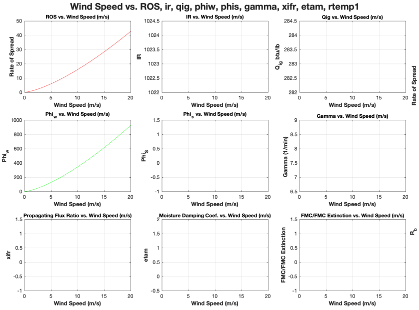

Figure: Rothermel Model

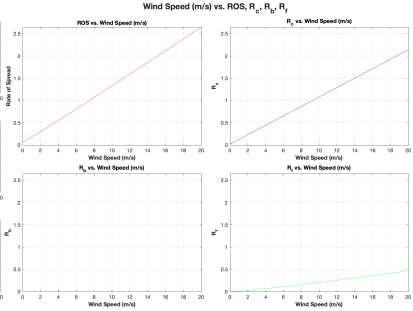

Figure: Balbi Model

Comparisons between the models

Slope Comparison

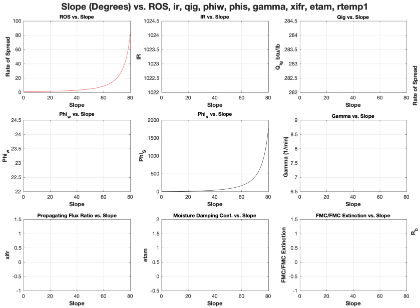

Figure: Rothermel Model

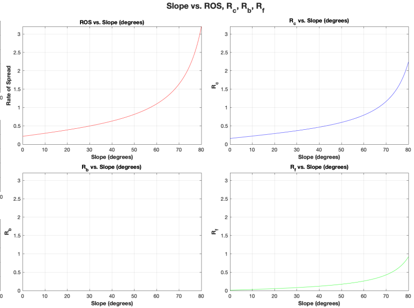

Figure: Balbi Model

Comparisons between the models

FMC Comparison

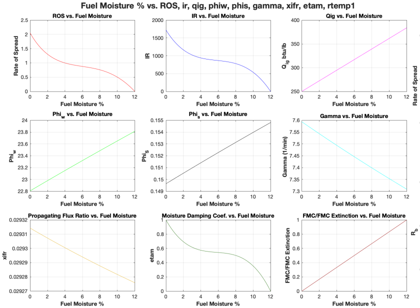

Figure: Rothermel Model

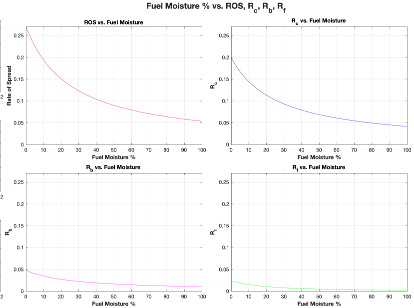

Figure: Balbi Model

Comparisons between the models

FMC Rothermel

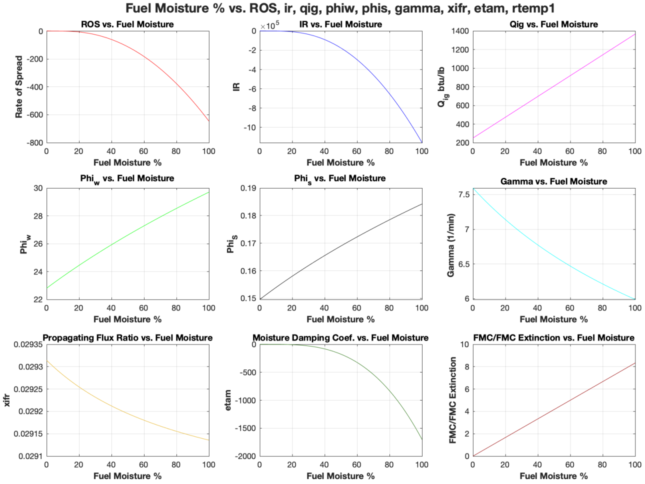

Figure: Rothermel model FMC without considering extinction FMC

Comparisons between the models

Fuel Height Comparison

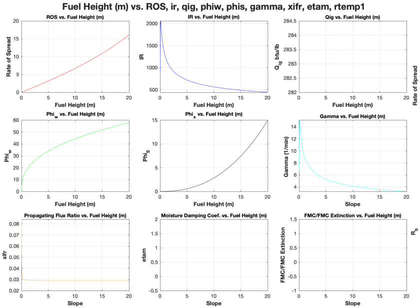

Figure: Rothermel Model

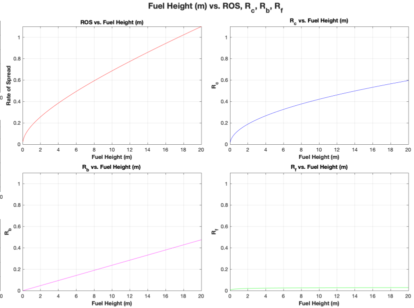

Figure: Balbi Model

Comparisons between the models

SAVR Comparison

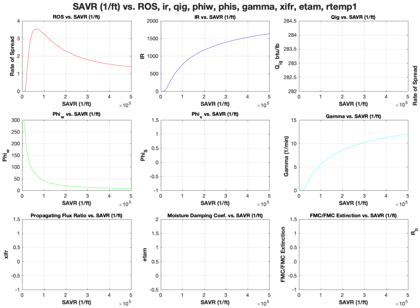

Figure: Rothermel Model

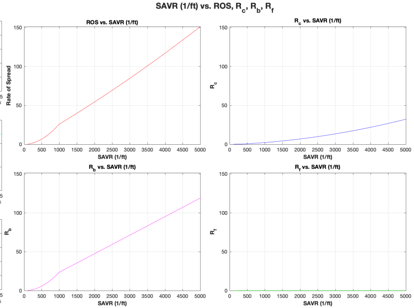

Figure: Balbi Model

References

Anderson, W. R., Catchpole, E. A. and Butler, B. W. [2010], 'Convective heat transfer in fire spread through fine fuel beds', *International Journal of Wildland Fire* **19**, 284–298.

Balbi, J. H., Chatelon, F. J., Morvan, D., Rossi, J. L., Marcelli, T. and Morandini, F. [2020], 'A convective-radiative propagation model for wildland fires', *International Journal of Wildland Fire* **29**.

Balbi, J. H., Rossi, J. L., Marcelli, T. and Santoni, P. A. [2007], 'A 3d physical real-time model of surface fires across fuel beds', *Combustion Science and Technology* **179**, 2511–2537.

Chatelon, F. J., Balbi, J. H., Cruz, M. G., Morvan, D., Rossi, J. L., Awad, C., Frangieh, N., Fayad, J. and Marcelli, T. [2022], 'Extension of the balbi fire spread model to include the field scale conditions of shrubland fires', *International Journal of Wildland Fire* **31**, 176–192.

Rothermel, R. C. [1972], *A mathematical model for predicting fire spread in wildland fuels*, Intermountain Forest and Range Experiment Station, Forest Service, United States Department of Agriculture.

Questions?

- Feel free to contact me with any further questions at: jeremy.benik@sjsu.edu

Thank you

Thank you!

- Here is a link to my codes if anyone wants to check them out
  - https://github.com/Jeremy-Benik/164/tree/main/Assignments/Final_Drafts/Codes