

Rothermel vs. Balbi rate of spread model

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Rothermel Model

Overview of the Rothermel Model

Introduction to the Rothermel ROS 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

Overview of the Rothermel Model

Introduction to the Rothermel ROS model

- ▶ 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

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

- ▶ 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
- ▶ $\left(\frac{\partial I_z}{\partial z} \right)_{z_c}$ = 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

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

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

$$I_R = -(\frac{dw}{dx})(\frac{dx}{dt})h \quad (4)$$

$$I_R D = R * h(W_n - W_r) \quad (5)$$

$$\Gamma = \Gamma' \eta_M \eta_s \quad (6)$$

$$\beta = \frac{\rho_b}{\rho_p} \quad (7)$$

$$\sigma = \frac{4}{d} \quad (8)$$

Evaluating Each Component

Every component for the Rothermel model

$$\Gamma' = \frac{\Gamma}{\eta_M \eta_S} \quad (9)$$

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

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

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

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

Final ROS Equation

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

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

$$\tan \beta_w = \frac{\nu_w}{u_{fl}} \quad (15)$$

$$\gamma = \alpha + \beta_s \quad (16)$$

$$\tan \beta_s = \frac{\nu_s}{u_{fl}} \quad (17)$$

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

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

Evaluating Each Equation

Every component for the Balbi model

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

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

$$\rho_a h \nu_u = v D \dot{\sigma}_{fu} \quad (22)$$

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

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

Evaluating Each Equation

Every component for the Balbi model

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

$$\sigma_{fu} c_{pfu} \frac{dT_{fu}}{dt} = R_b + R_{fl} - \Delta h_w \frac{d\sigma_w}{dt} \quad (26)$$

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

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

Evaluating Each Equation

Every component for the Balbi model

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

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

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

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

Final Balbi ROS Equation

$$R = R_c + R_b + R_f \quad (33)$$

Comparing the Models

Comparisons between the models

Wind Speed Comparison

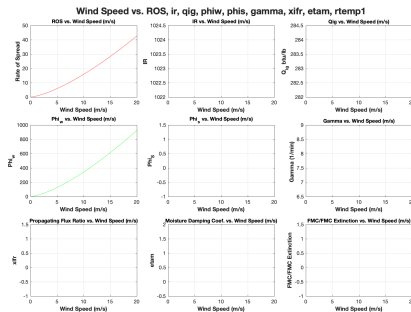


Figure: Rothemel Model

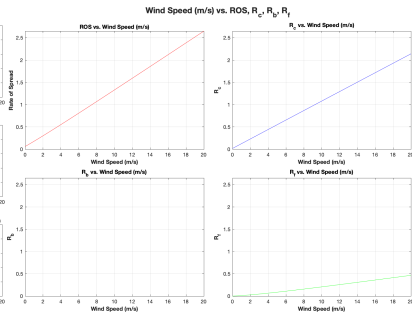


Figure: Balbi Model

Comparisons between the models

Slope Comparison

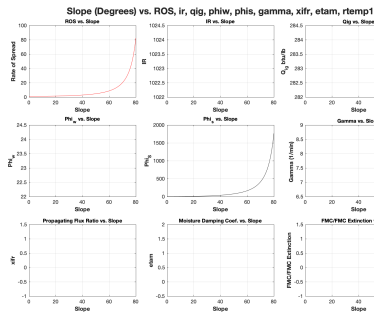


Figure: Rothmel Model

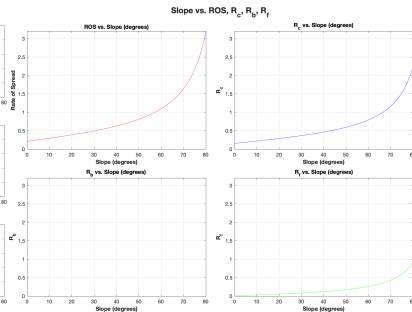


Figure: Balbi Model

Comparisons between the models

FMC Comparison

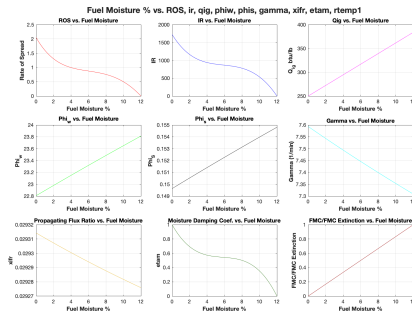


Figure: Rothmel Model

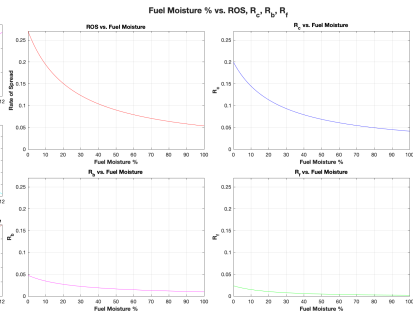


Figure: Balbi Model

Comparisons between the models

FMC Rothermel

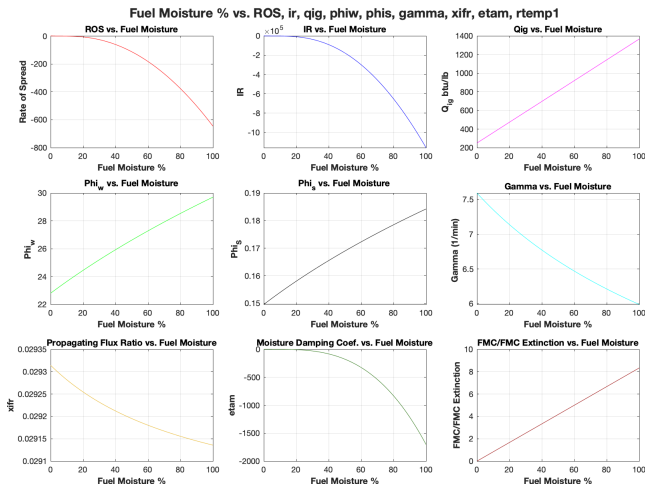


Figure: Rothermel model FMC without considering extinction FMC

Comparisons between the models

Fuel Height Comparison

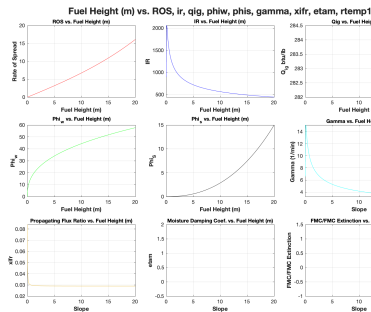


Figure: Rothmel Model

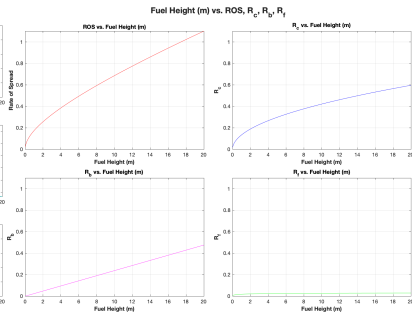


Figure: Balbi Model

Comparisons between the models

SAVR Comparison

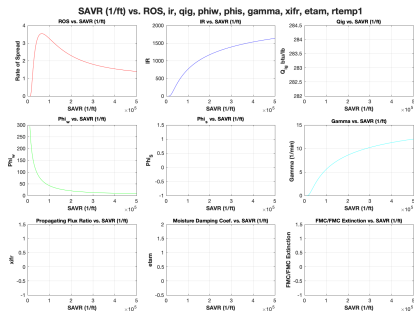


Figure: Rothemel Model

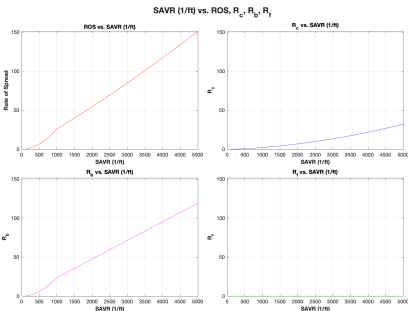


Figure: Balbi Model

References

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- 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:
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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