Rothermel vs. Balbi rate of spread model

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Outline

- ▶ 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
- ▶ To formulate the model, many assumptions and simplifications are necessary to reduce the initial equation (Equation 1) down to a more manageable calculation

Initial Rothermel rate of spread equation

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

- ▶ 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(the amount of fuel per unit volume of the fuel bed raised to ignition ahead of the advancing fire), lb./ft.3
- ▶ Q_{ig} = heat of preignition (the heat required to bring a unit weight of fuel to ignition),. 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 base model

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

$$I_R = -(\frac{\mathrm{d}w}{\mathrm{d}x})(\frac{\mathrm{d}x}{\mathrm{d}t})h \tag{3}$$

$$I_R D = R * h(W_n - W_r) \tag{4}$$

$$\Gamma = \Gamma^{'}\eta_M\eta_s \tag{5}$$

$$\beta = \frac{\rho_b}{\rho_p} \tag{6}$$

$$\sigma = \frac{4}{d} \tag{7}$$

Evaluating Each Component
Every component for the base model

$$\Gamma' = \frac{\Gamma}{\eta_M \eta_S} \tag{8}$$

$$\Gamma' = \Gamma'_{max}(\frac{\beta}{\beta_{op}})^A exp[A(1 - \frac{\beta}{\beta_{op}})] \tag{9}$$

$$(I_P)_o = R_0 \rho_b \epsilon Q_{ig} \tag{10}$$

$$\phi_W = CU^B(\frac{\beta}{\beta_{op}})^{-E} \tag{11}$$

$$\phi_S = 5.275\beta^{-.3}(tan\phi)^2 \tag{12}$$

- There are multiple versions of the Balbi model
- The first model being created in 2007 and the last revision made this year (2022)
- Throughout the different versions, improvements have been made to the model 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

- 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

$$\tan \beta_w = \frac{\nu_w}{u_{fl}} \tag{13}$$

$$\gamma = \alpha + \beta_s \tag{14}$$

$$\tan \beta_s = \frac{\nu_s}{u_{fl}} \tag{15}$$

$$H = H^* Q^{\frac{2}{5}} = H^* (\Delta h_{fu} \sigma_{fu} c)^{\frac{2}{5}} \tag{16}$$

$$\rho_g \frac{\partial u}{\partial t} = (\rho_a - \rho_g)g \tag{17}$$

$$u_{fl} = Q^{\frac{1}{5}} \sqrt{(\frac{T_{fl}}{T_a} - 1)gH^*} \tag{18}$$

$$\rho_g u_{fl} l = \rho_{ga} h \nu_u + D \dot{\sigma}_{fu} \tag{19}$$

$$\rho_a h \nu_u = \upsilon D \dot{\sigma}_{fu} \tag{20}$$

$$T_{fl} = T_a + \frac{(1-\chi)Q}{(\upsilon+1)D\dot{\sigma}_{fu}c_{pg}} = T_a + \frac{(1-\chi)\Delta h_{fu}}{(\upsilon+1)c_{pg}} \tag{21}$$

$$R_b = \sigma T_{fl}^4 \mathrm{d}(\delta - x) \tag{22}$$

$$R_{fl} = \epsilon_{fl}\sigma \frac{T_{fl}^4}{2}(1 - \cos\theta) \tag{23}$$

$$\sigma_{fu}c_{pfu}\frac{\mathrm{d}T_{fu}}{\mathrm{d}t} = R_b + R_{fl} - \Delta h_w \frac{\mathrm{d}\sigma_w}{\mathrm{d}t} \tag{24}$$

$$c_1 = \frac{\sigma T_{fl}^4 \mathrm{d}\delta^2}{2\sigma_{fu}(c_{pfu}(T_{ig} - T_a) + \Delta h_w \eta)} \tag{25}$$

$$c_h = c_l + \frac{\epsilon_{fl}\sigma T_{fl}^4 H}{2\sigma_{fu}(c_{pfu}(T_{ig} - T_a) + \Delta h_w \eta)}(1 + \sin\gamma - \cos\gamma) \tag{26}$$

Evaluating Each Equation

Every component for the base model

$$\varepsilon_{fl}\sigma T_{fl}^4 = \chi Q/H \tag{27}$$

$$\phi_c = \frac{\Delta H}{2\tau_0}\sigma\,smin(h,\delta)\tan\gamma_c \tag{28}$$

$$\tan\gamma_c = \tan\alpha + \frac{U(L)}{u_c} \tag{29}$$

$$R_c = a_M min(\frac{W_0}{50},1) * \frac{\Delta H\rho_a T_a s\sqrt{h}}{2q(s_t+1)\rho_v T}(\frac{(s_t+1)\rho_v T}{\tau_0\rho_a T_a}*$$
$$min(S,\frac{2\pi S}{S_t}\tan\alpha + U\exp(-\frac{\beta_t}{min(\frac{W_0}{50},1)}R)) \tag{30}$$

Comparisons between the models

Wind Speed Comparison
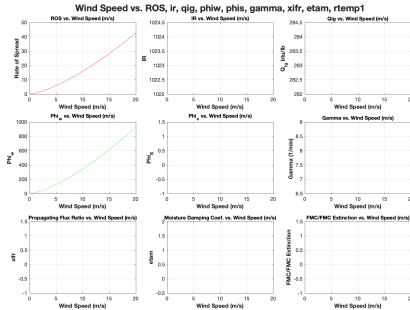
Figure: Rothermel Model
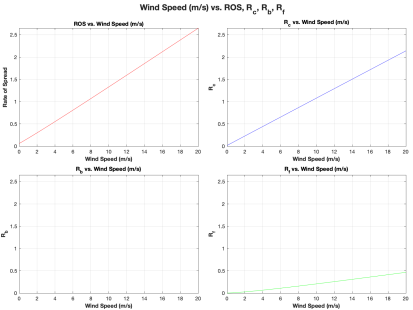
Figure: Balbi Model

Comparisons between the models
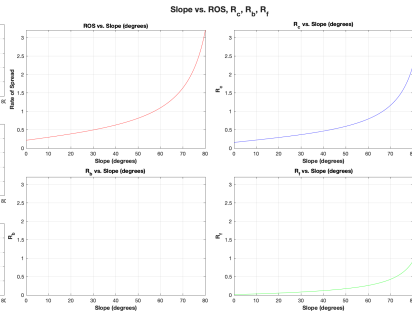
Slope Comparison
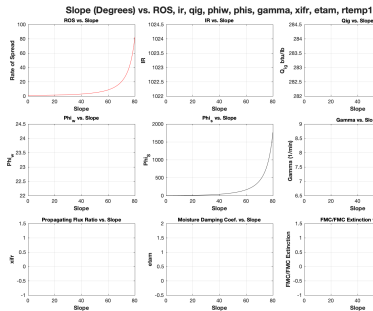
Figure: Rothermel Model

Figure: Balbi Model

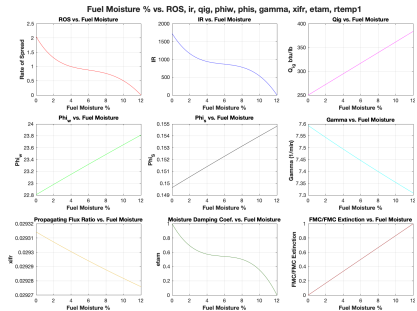# Comparisons between the models

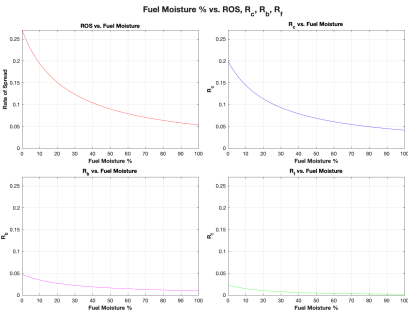## FMC Comparison

Figure: Rothermel Model

Figure: Balbi Model

Comparisons between the models
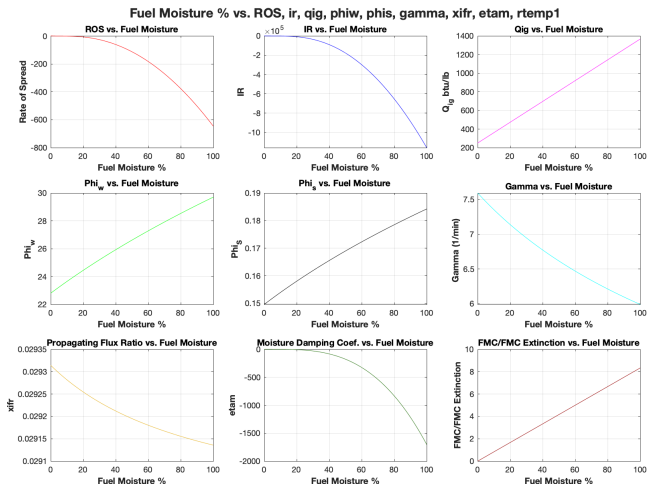## FMC Rothermel

Figure: Rothermel model FMC without considering extinction FMC
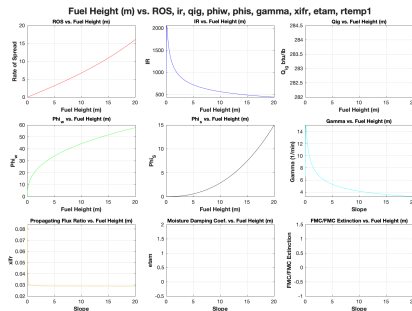
Comparisons between the models
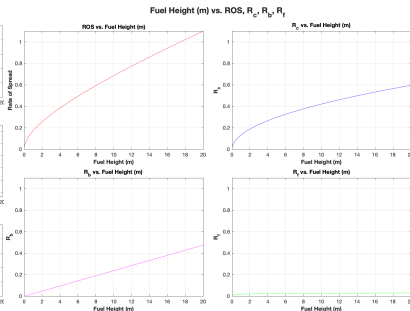
Fuel Height Comparison

Figure: Rothermel Model

Figure: Balbi Model

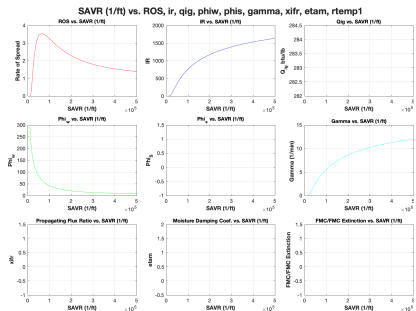# Comparisons between the models
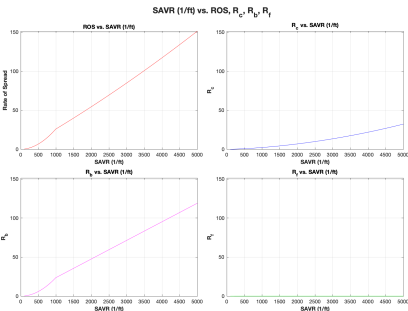
SAVR Comparison

Figure: Rothermel Model

Figure: Balbi Model

References

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