Role of vegetation density on wildland fire

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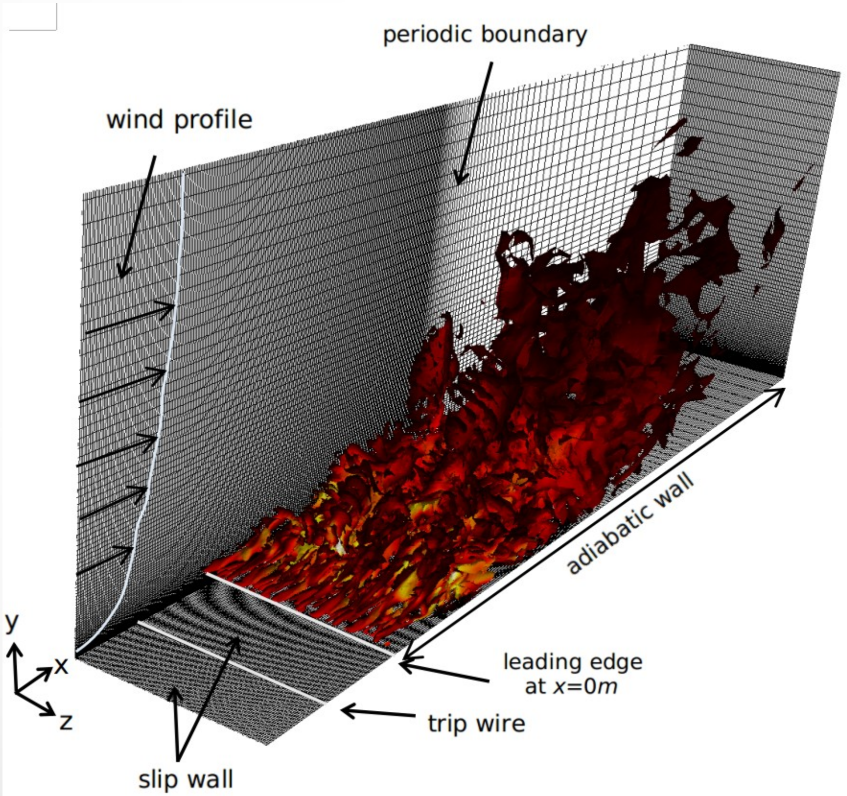
- Is Froude number (*Fr*), Byram number (*Nc*) or other dimensionless number enough to describe fire behaviour?
- Lack of understanding of the effect of vegetation density (*CdLAI*) on

  a. Fire regime transition from plume dominated to wind driven.

  b. Heat transfer mechanism from radiative to convective heat transfer to ignite unburnt fuel.
- Lack of understanding of the configuration space {*Nc, CdLAI*} effect on fire behaviour.

Sub-grid small-scale flame models is essential for large- or giga-scale fire modelling - *e.g.*, coupled fire-atomosphere modelling

(*Verma S. and Trouve A., 2018*)



Visualization of the configuration using instantaneous iso-contour of Q-criterion at $2(s^{-2})$, clipped to $x_{max} = 2.5m$, $y_{max} = 1m$.

Solver: Simplified ForestFireFoam (FFF) developed from FireFoam at M2P2 Lab.

Features of FFF:

Multiphase turbulent combustion modelling with sub-models improvement for:

a. Pyrolysis; *b.* Evaporation; *c.* Char oxidation/Smoldring

d. Turbulent combustion:

- WALE;
- EDC;

e. Radiation: fvDOM

Utilities for pre- or post-processing:

- blockMesh; setFields; topoSet; funkySet, swak4Foam, paraview *etc.*

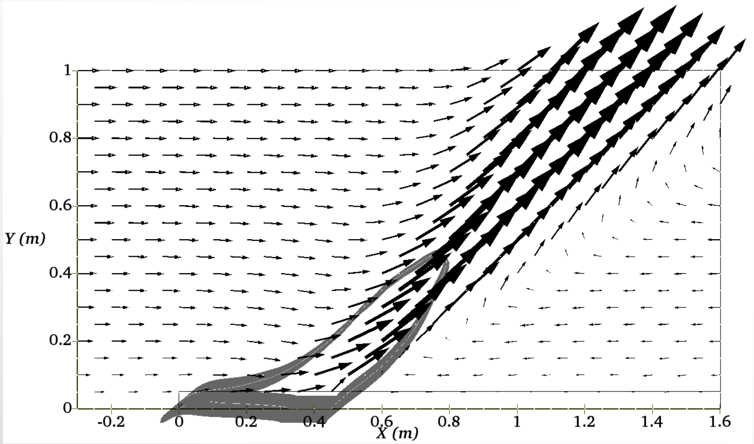
Question:

How does the configuration space {N_C, *CdLAI*} determine flame regime (wind or plume dominated) and heat transfer to solid particle (radiation or convection governed)?

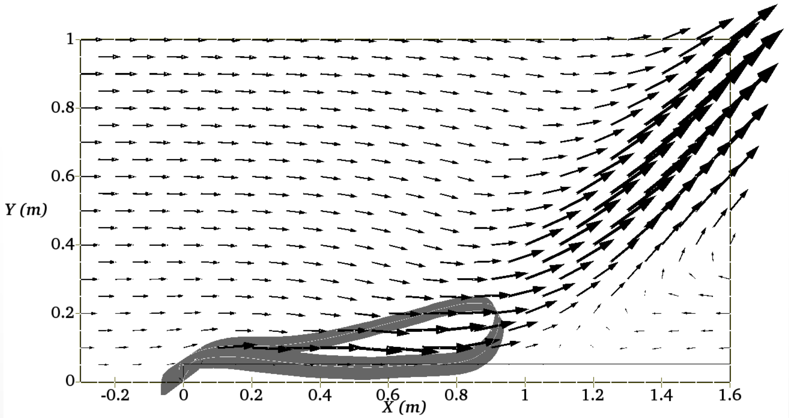
configuration space {N_C, *CdLAI*}

- Byram convective number: $N_C = \frac{2gI}{\rho_\infty (U_\infty - ROS)^3 C_P T_\infty}$ (Nelson, 2015)
  - $N_C < 2$ Wind, convection driven
  - $2 < N_C < 10$ Mixed
  - $N_C > 10$ Plume, radiation dominated
- $CdLAI$ (Lamorlette et al. 2015)
  - Drag Coefficient: C_d
  - Leaf area index: $LAI \longleftrightarrow \alpha_s \sigma_s H_F / 2$
    - Solid volume of fraction: α_s
    - Surface to volume ratio: σ_s
    - Vegetation height: H_F

500*K* 3D flame contour and velocity vectors:



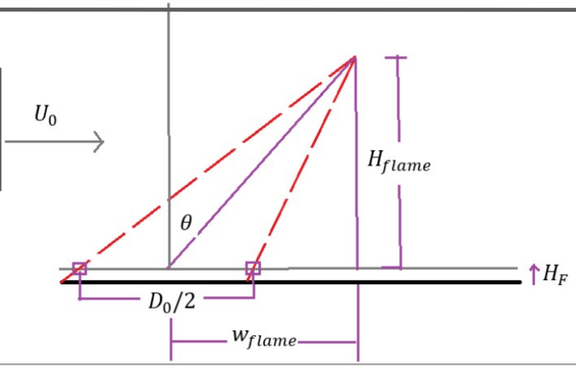
Nc=20, CdLAI=0.01



Nc=20, CdLAI=0.5

Nc alone is insufficient to describe fire behaviour!

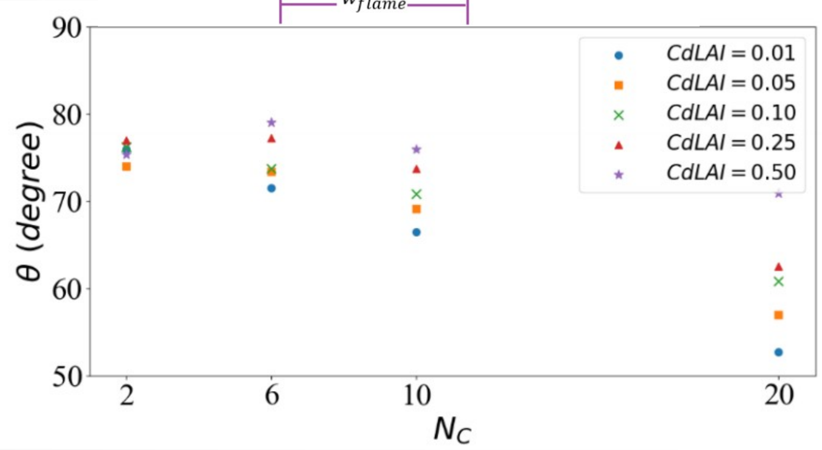
Flame tilt angle definition



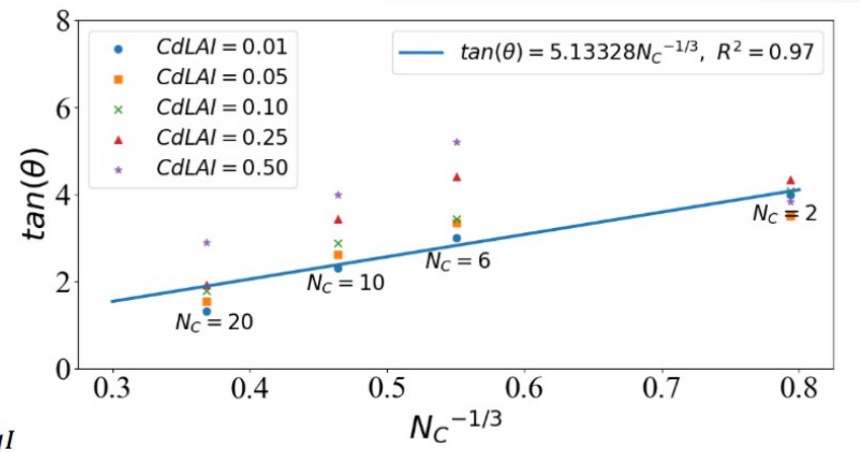
Model correlations		Fuel
$tan(\theta) = C \times (\frac{2T_0}{T_f})^{1/5} \times Ka^{-1/5}$	(1)	Heptane, Ethanol, and Acetone
$tan(\theta) = \begin{cases} C_1 \times \alpha^{1/2} N_C^{-1/3} \ (N_C < 10) \\ C_2 \times \eta^2 N_C^{-2/3} \ (N_C > 10) \end{cases}$	(2) (3)	Long leaf pine, slash pine litter, *etc.*

(Hu et al. 2013 Tang et al. 2015)

(Nelson, 2003)



fitting?



$$N_C = \frac{2gI}{\rho_\infty (U_\infty - ROS)^3 C_P T_\infty}$$

$$R_i = g \Delta T_f D / T_f U_0^2$$

$$K_a = N_C \times R_i$$

$$tan(\theta) = C \times [2 \times \frac{\rho_0 C_{p,0} T_0 U_0^3}{2gI} \times \frac{U_0^2 T_f}{g(T_f - T_0)D} \times \frac{T_0}{T_f}]^{1/5} = C \times (\frac{2T_0}{T_f})^{1/5} \times [K_a]^{-1/5}$$

Interestingly, $Ka^{-1/5} \sim N_C^{-1/3}$, equation (1) and (2) are essentially the same, only applicable to N_C<10, role of *CdLAI*?

Finding (1)

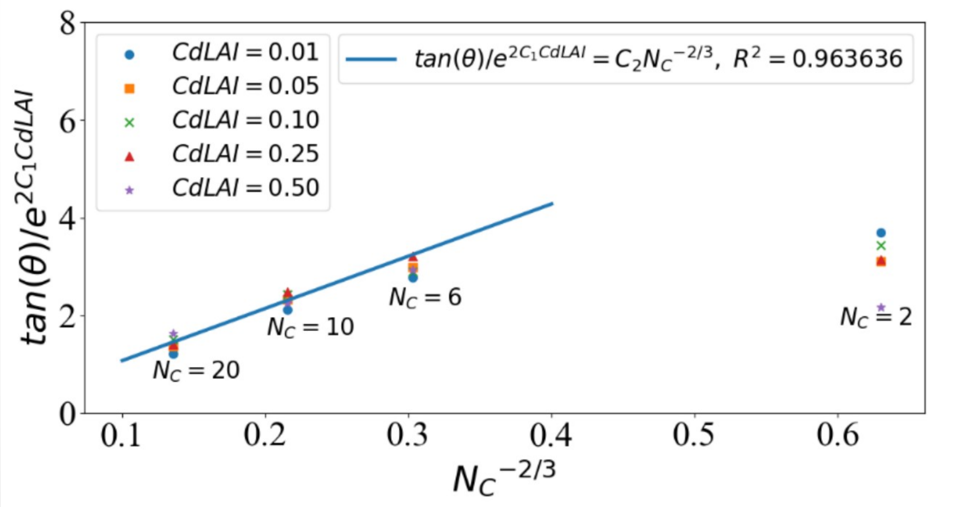
New mathematical correlation is required!

$$\tan(\theta) = \frac{F_d}{F_b} \begin{cases} \frac{C_d \rho_0 U_e^2 HL}{\rho w_0^2 HL} \sim C_2 \times \eta^2 N_C^{-2/3} \ (N_C > 10) & (3) \\ \frac{\rho_0 U_e^2 HL}{\rho w_0^2 HL} = \frac{\rho_0 e^{(2C_1 CdLAI)} U_0^2 HL}{\rho w_0^2 HL} = C_2 e^{2C_1 CdLAI} \times N_C^{-2/3} & (4) \end{cases}$$

(3) where $\eta = U_e/U_0$ (Nelson, 2003) — Old

(4) where $\begin{cases} \ln\eta = C_1 CdLAI \text{ or } \eta = e^{(C_1 CdLAI)} \\ U_e = e^{(C_1 CdLAI)} U_0 \end{cases}$ — New

Finding (2)

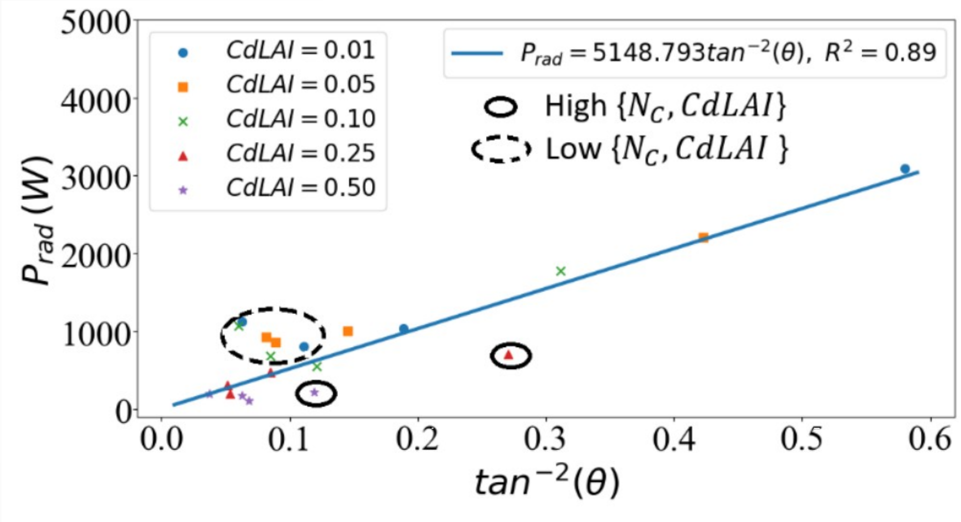


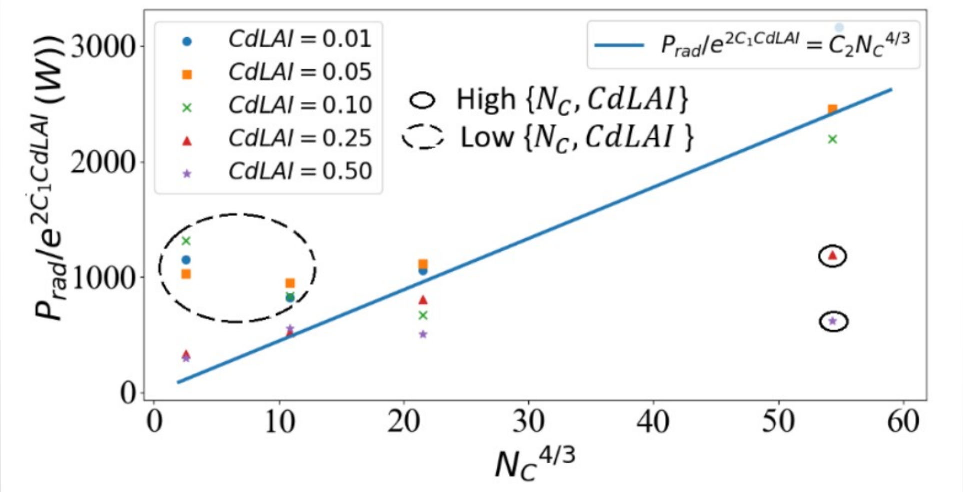
Importance of configuration space {N_C, $CdLAI$} highlighted!

Perfect fitting for $N_C > 10$
Good fitting for $N_C > 6$

For $C_1 = 0.5366287$, $C_2 = 10.76685369$

New mathematical correlation is required!





Definition of radiative heat power:

$$P_{rad} = \int Q_{rad}^{s} dv \,/ CdLAI$$

$$P_{rad} = 5148.793tan^{-2}(\theta) \text{ with } R^2 = 0.89$$

$$P_{rad} = C_2 e^{2C_1 CdLAI} N_C^{4/3}$$

With $C_1 = -1.0732574$ and $C_2 = 44.41481$

- Effect of vegetation density (*CdLAI*) is highlighted.
- Flame tile angle ~ directly related to *CdLAI*, inversely related to N_c.
- Radiative heat power ~ directly related to N_c, inversely related to *CdLAI*.
- Fitting with experimetanl data needed to validate proposed model correlations.

Thank You