Dynamically-Coupling Winds to the Fire-Front in the Wildland Urban Interface

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Wildfire Modeling

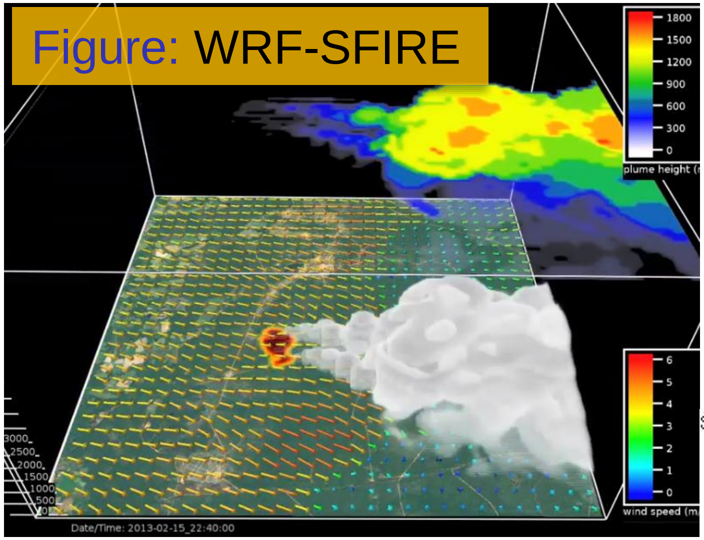


Figure: WRF-SFIRE

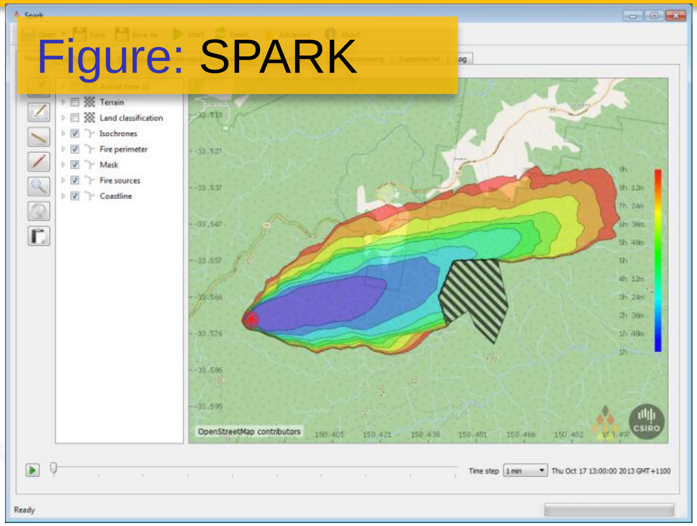


Figure: SPARK

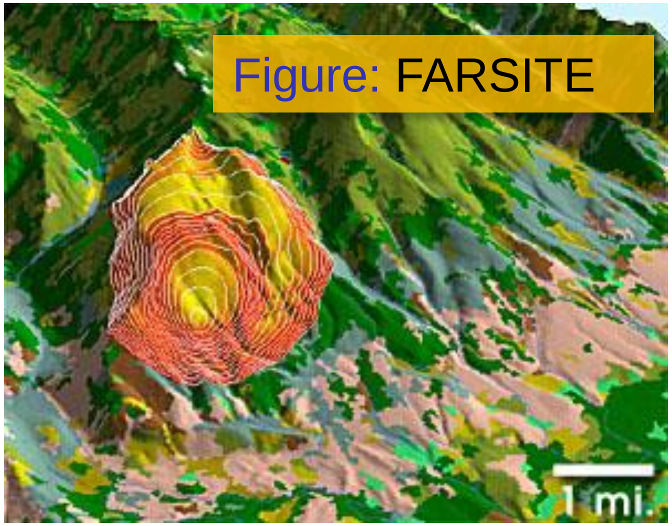


Figure: FARSITE

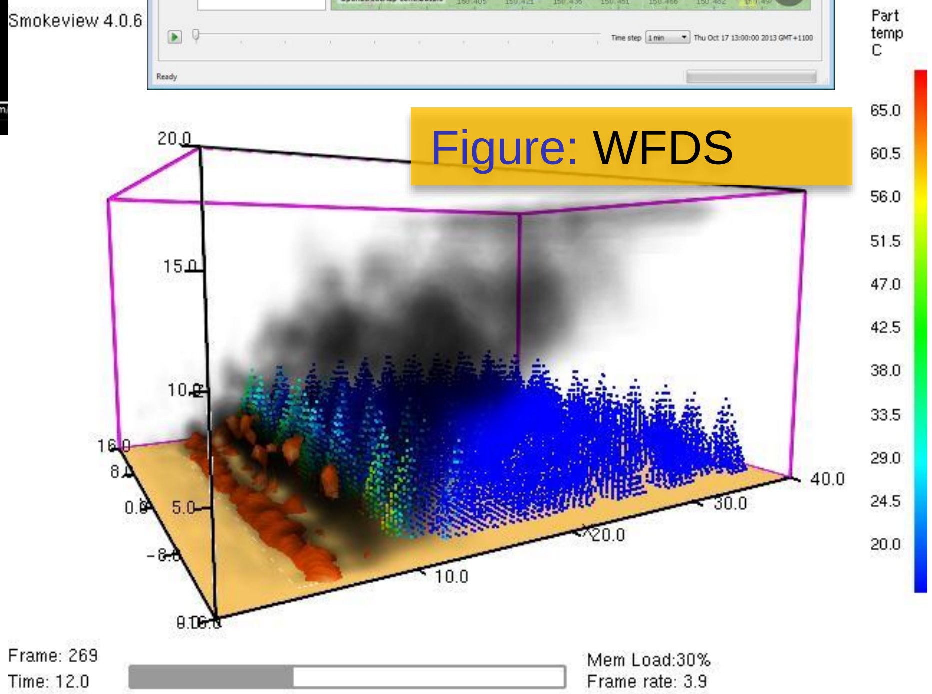
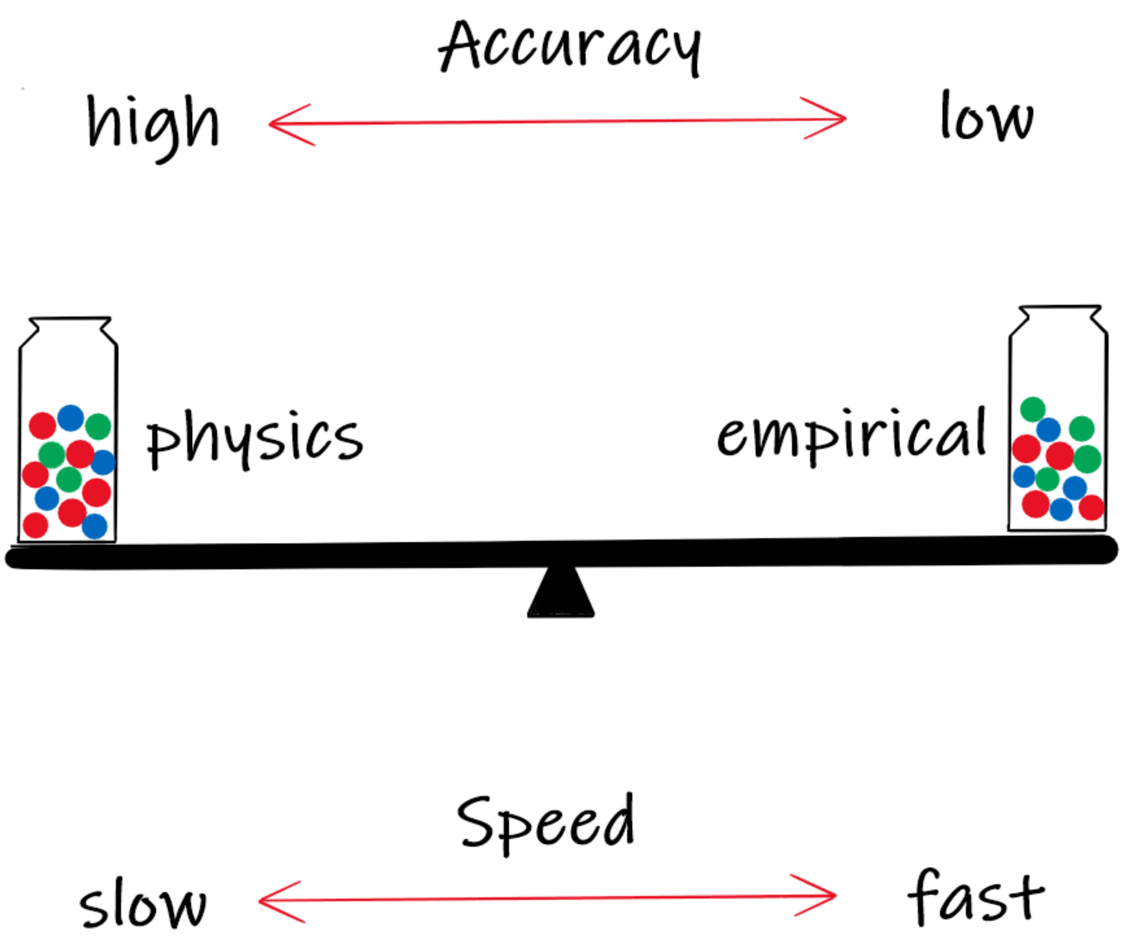


Figure: WFDS

Wildfire Modeling



QES

QES: Quick Environmental Simulations

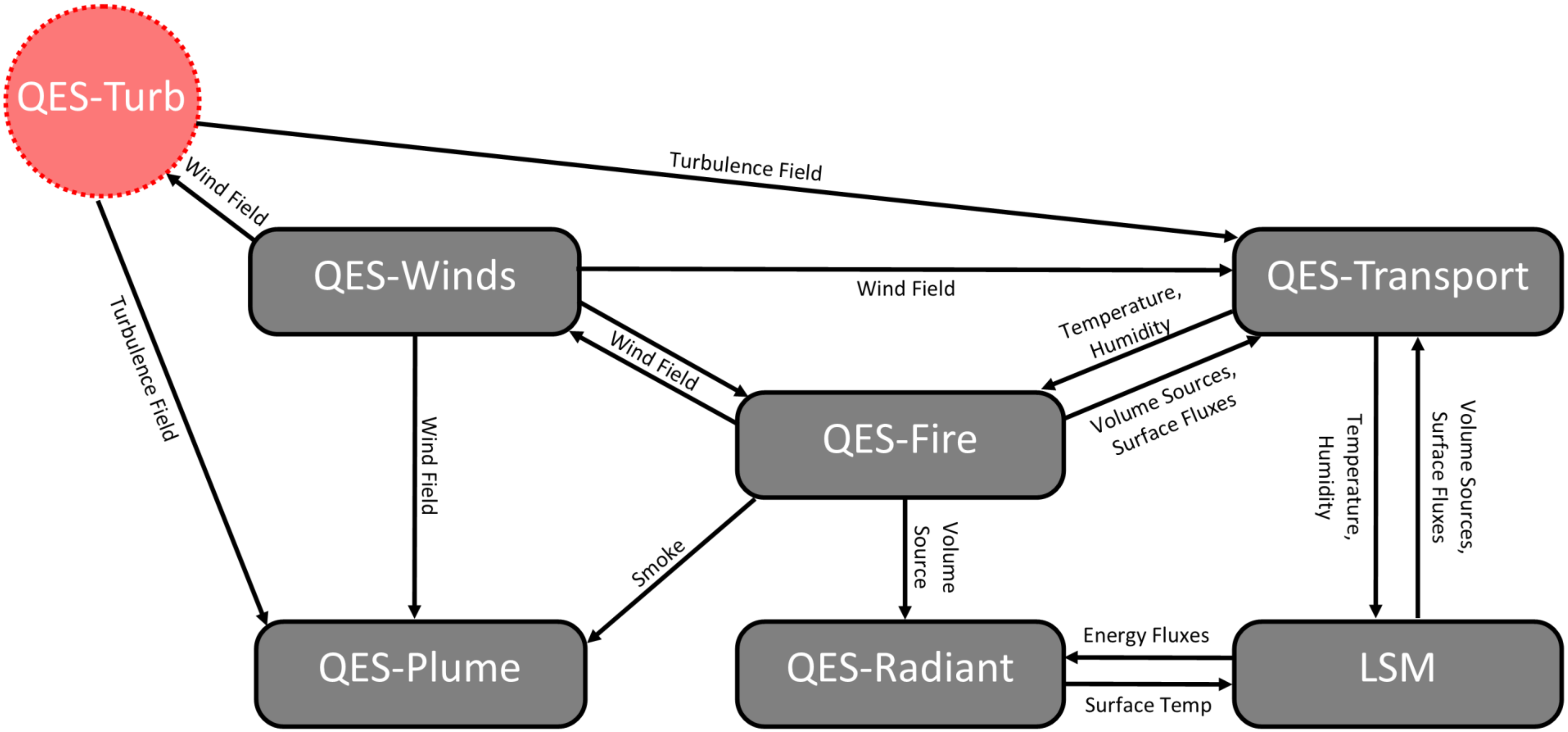


Figure: QES Modules

QES-Winds

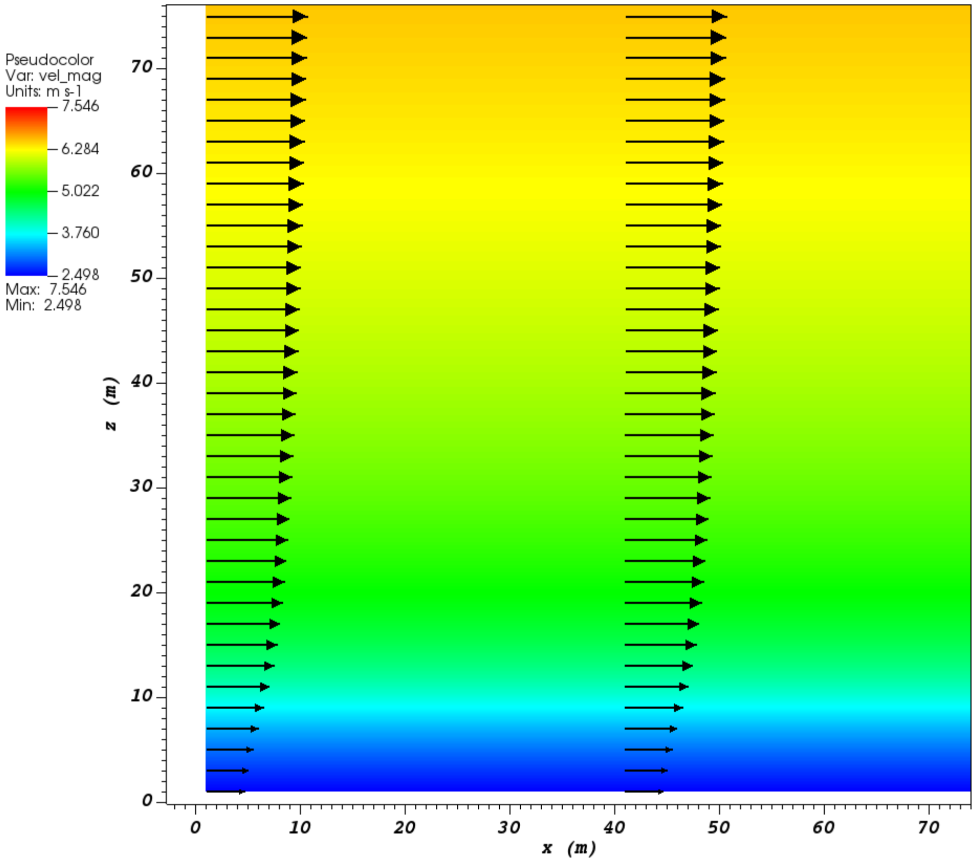
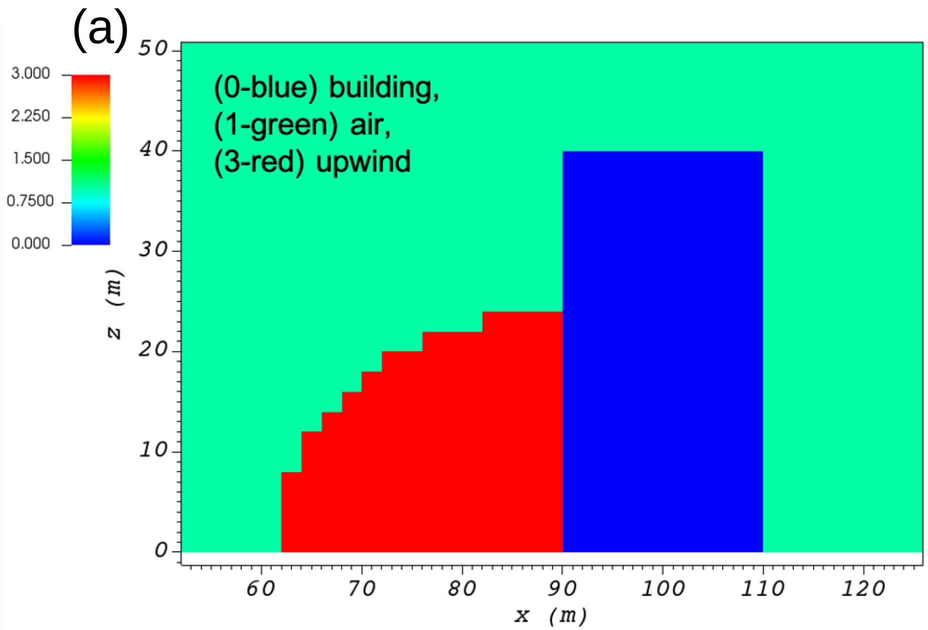


Figure: Initial wind field. [Bozorgmehr et. al., 2021]

QES-Winds



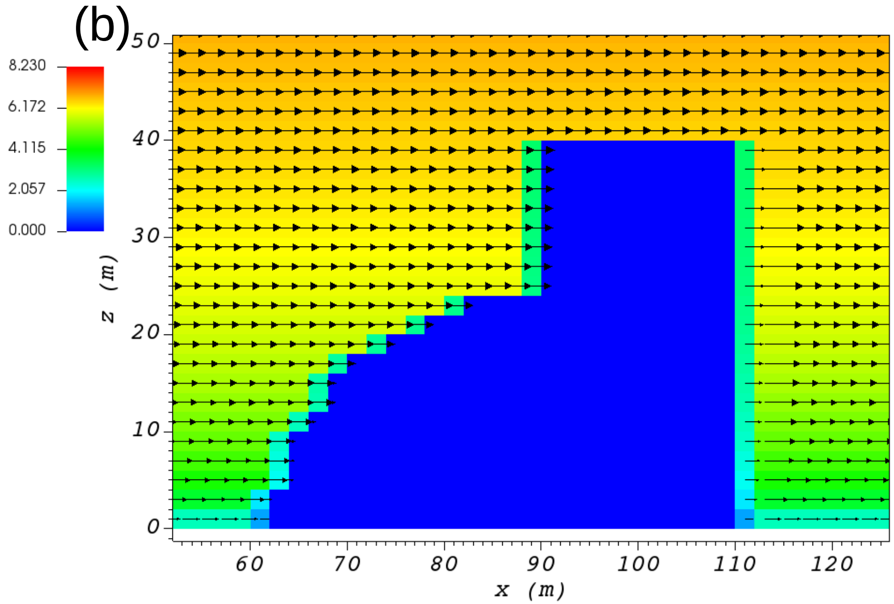


Figure: (a) Cell type, (b) Prescribed velocity. [Bozorgmehr et. al., 2021]

QES-Winds

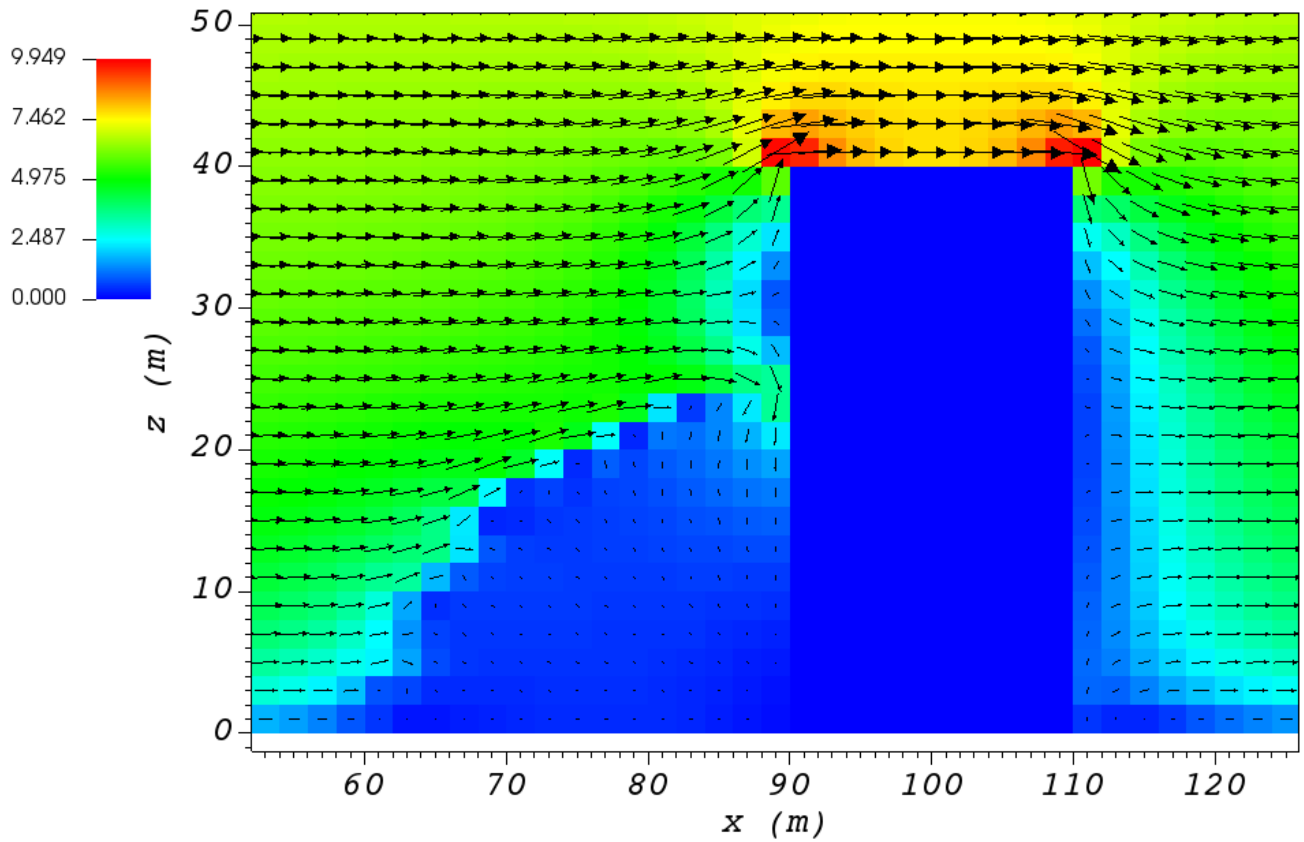
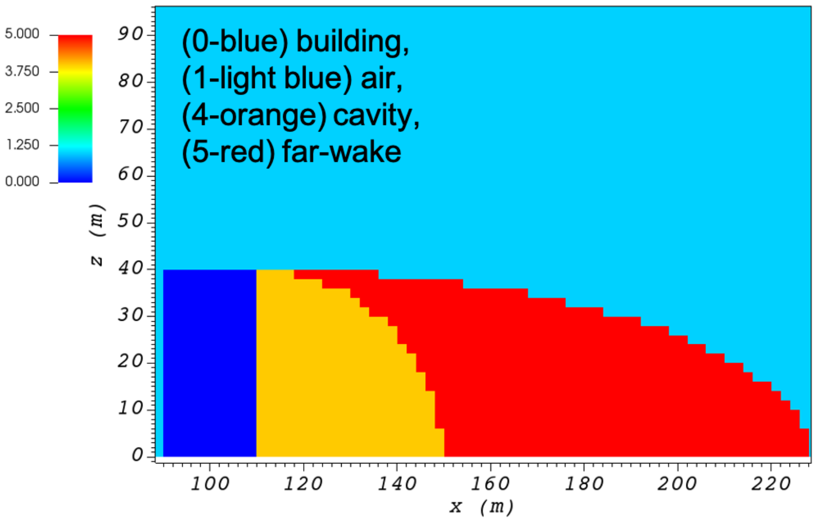
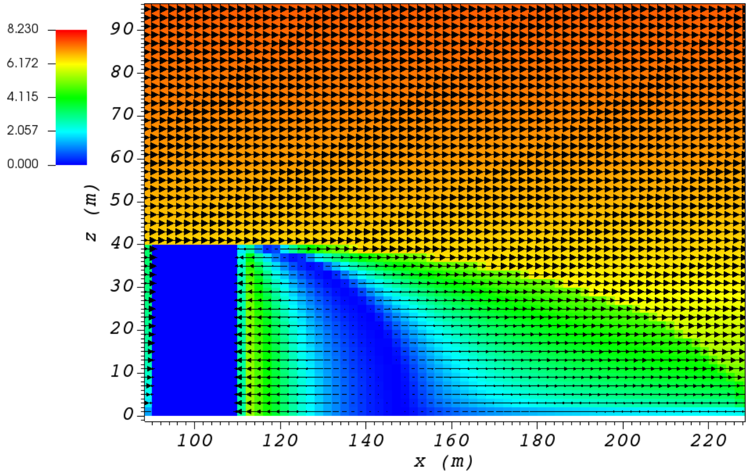


Figure: Final velocity. [Bozorgmehr et. al. , 2021]

QES-Winds





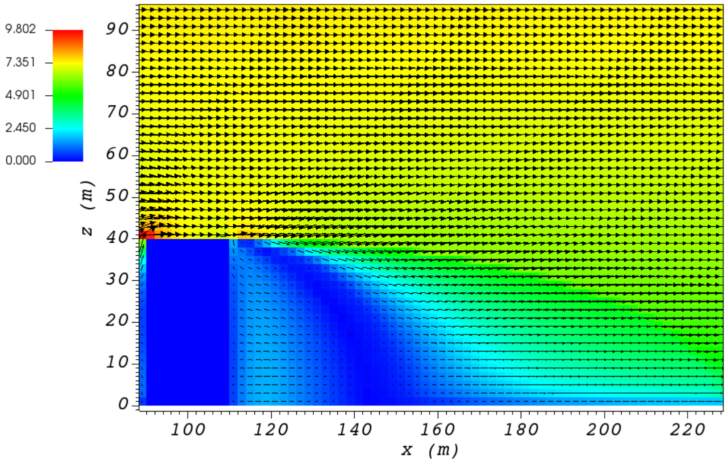
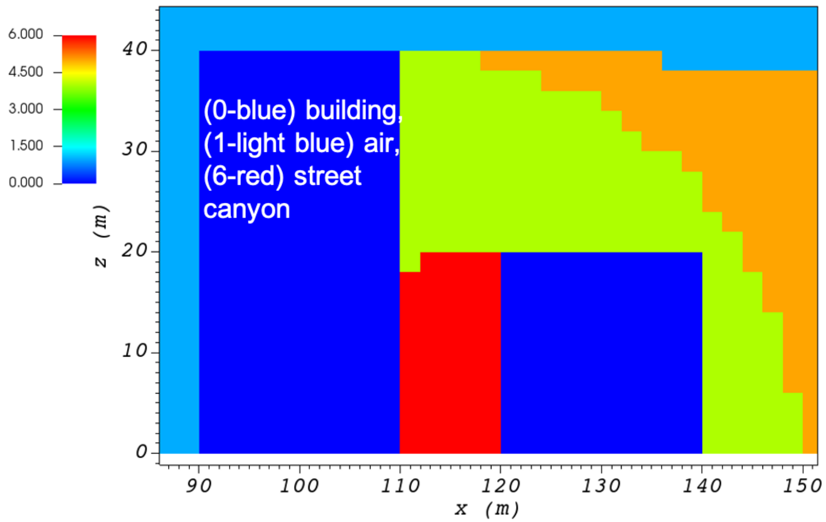
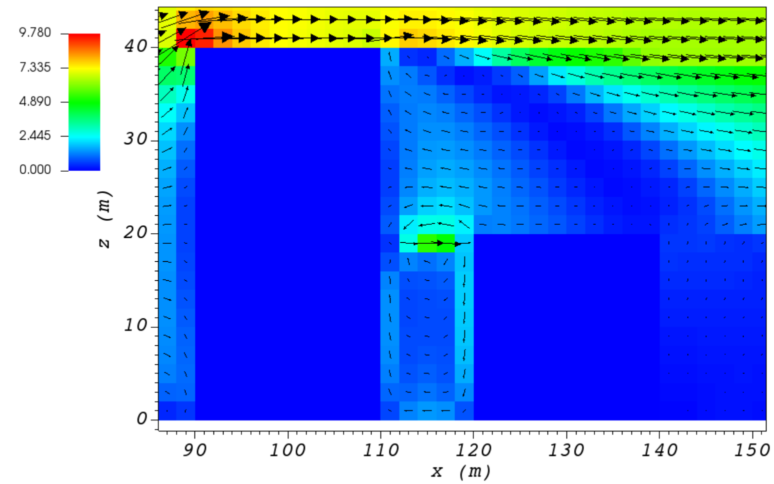


Figure: Building wake region. [Bozorgmehr et. al., 2021]

QES-Winds





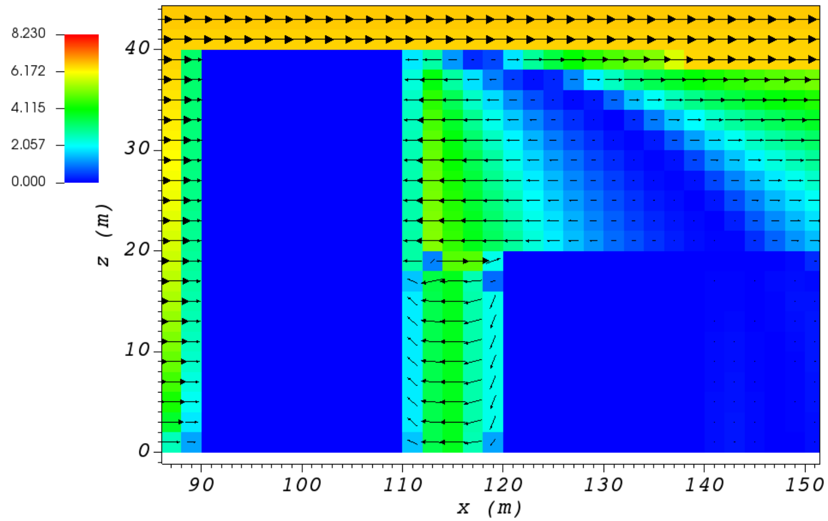


Figure: Street canyon. [Bozorgmehr et. al., 2021]

Canopy Parameterizations

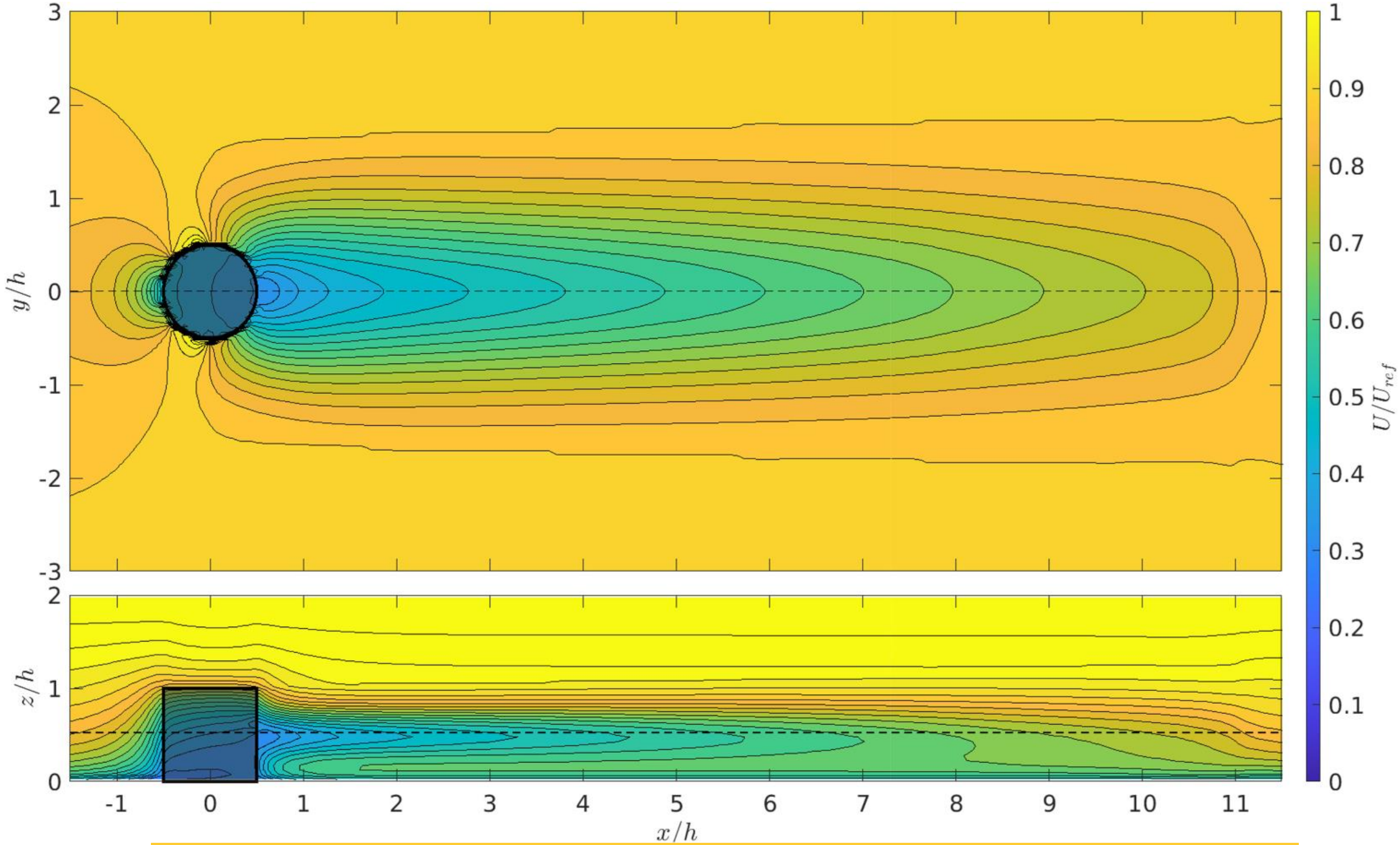
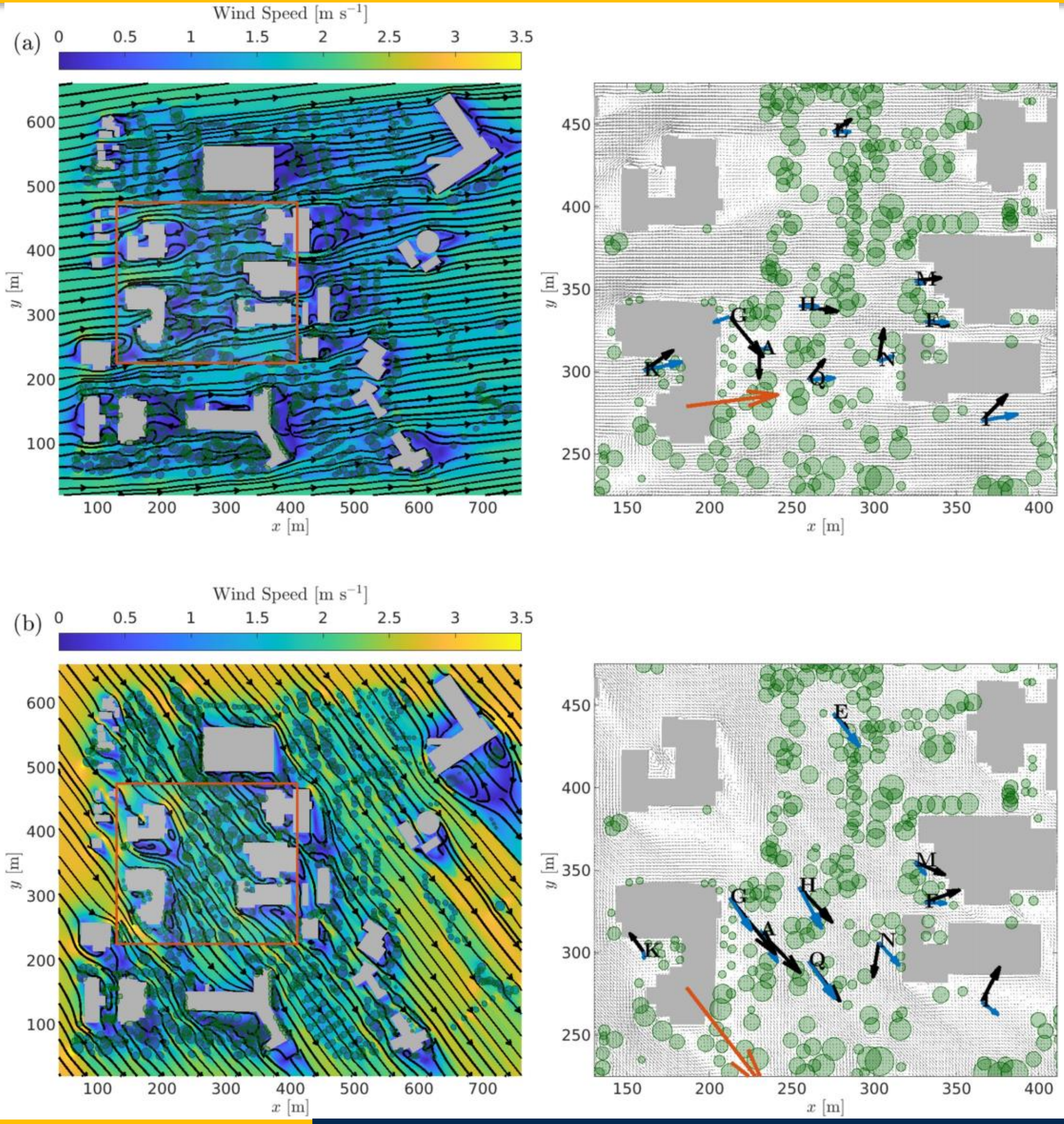


Figure: Nondimensional velocity downstream of an isolated tree. [Margairaz et.al., 2022]

Canopy Parameterizations

Figure: QES-Winds modeling of isolated trees in an urban environment. [Margairaz et.al., 2022]



Buoyant Plume

- A non-dimensional velocity is calculated as the superposition of solenoidal and potential non-dimensionalized velocities
- These velocities are non-dimensionalized by the heat flux

$$L_c \equiv \left(\frac{\dot{Q}_0}{\rho_0 c_p T_0 \sqrt{g}} \right)^{2/5} , \quad (1)$$

$$\vec{V}_c \equiv \left(\frac{g^2 \dot{Q}_0}{\rho_0 c_p T_0} \right)^{1/5} \quad (2)$$

Single Fire-Plume Domains

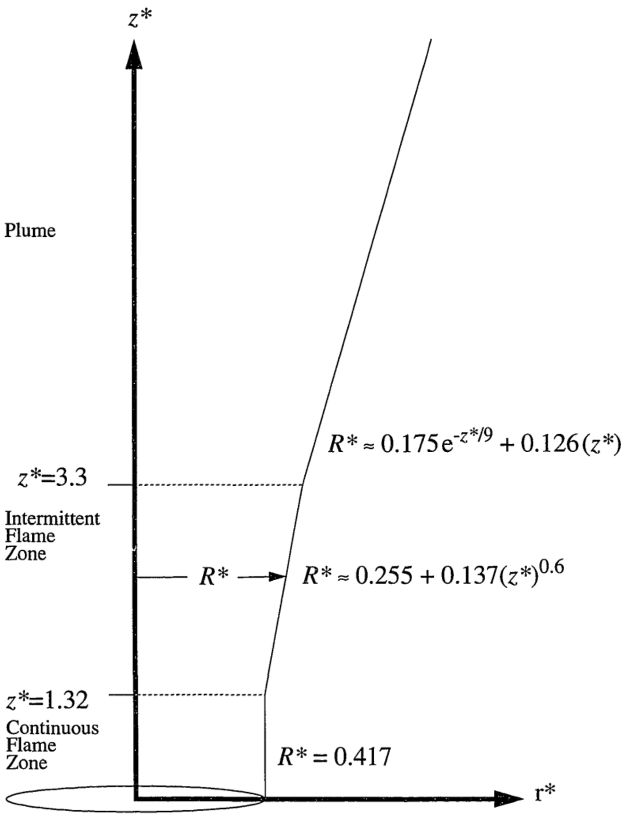


Figure: Single plume scaled by heat flux. [Trelles, 1995]

Buoyant Plume

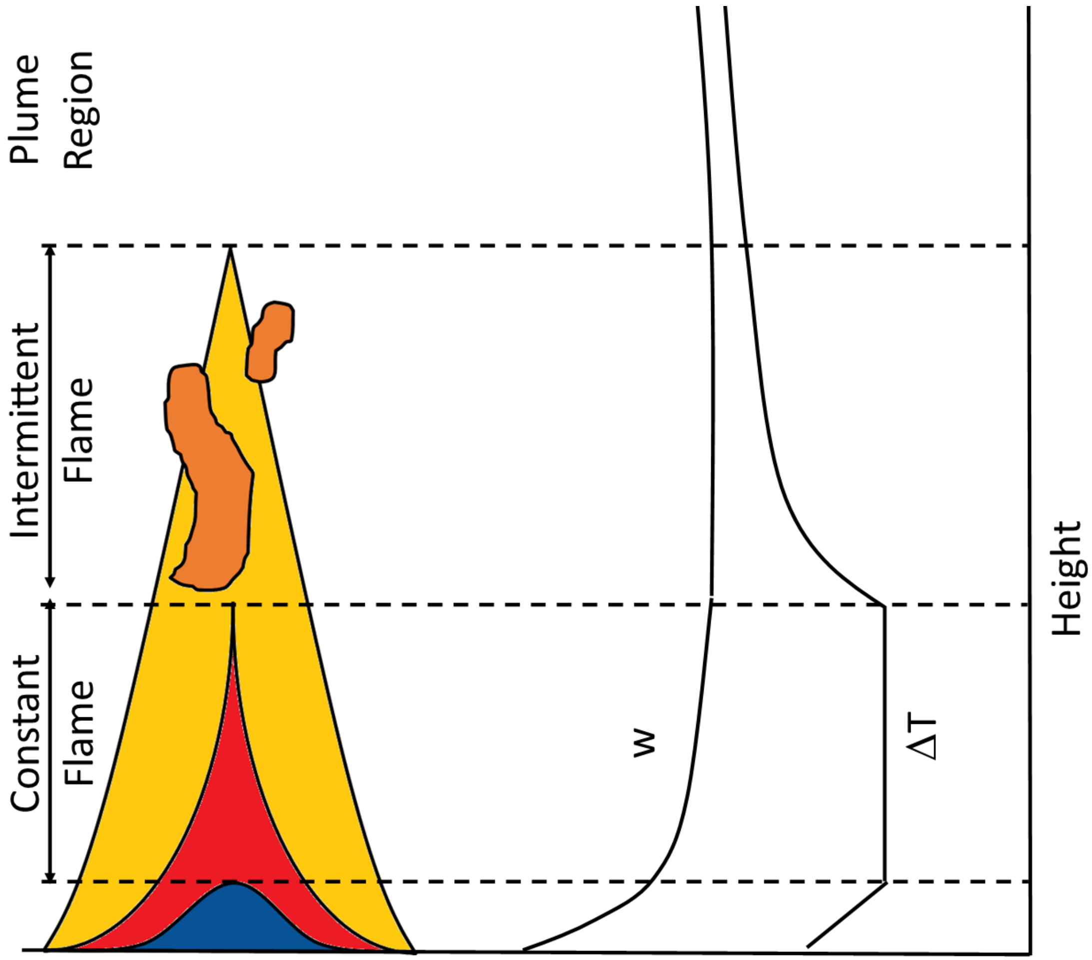
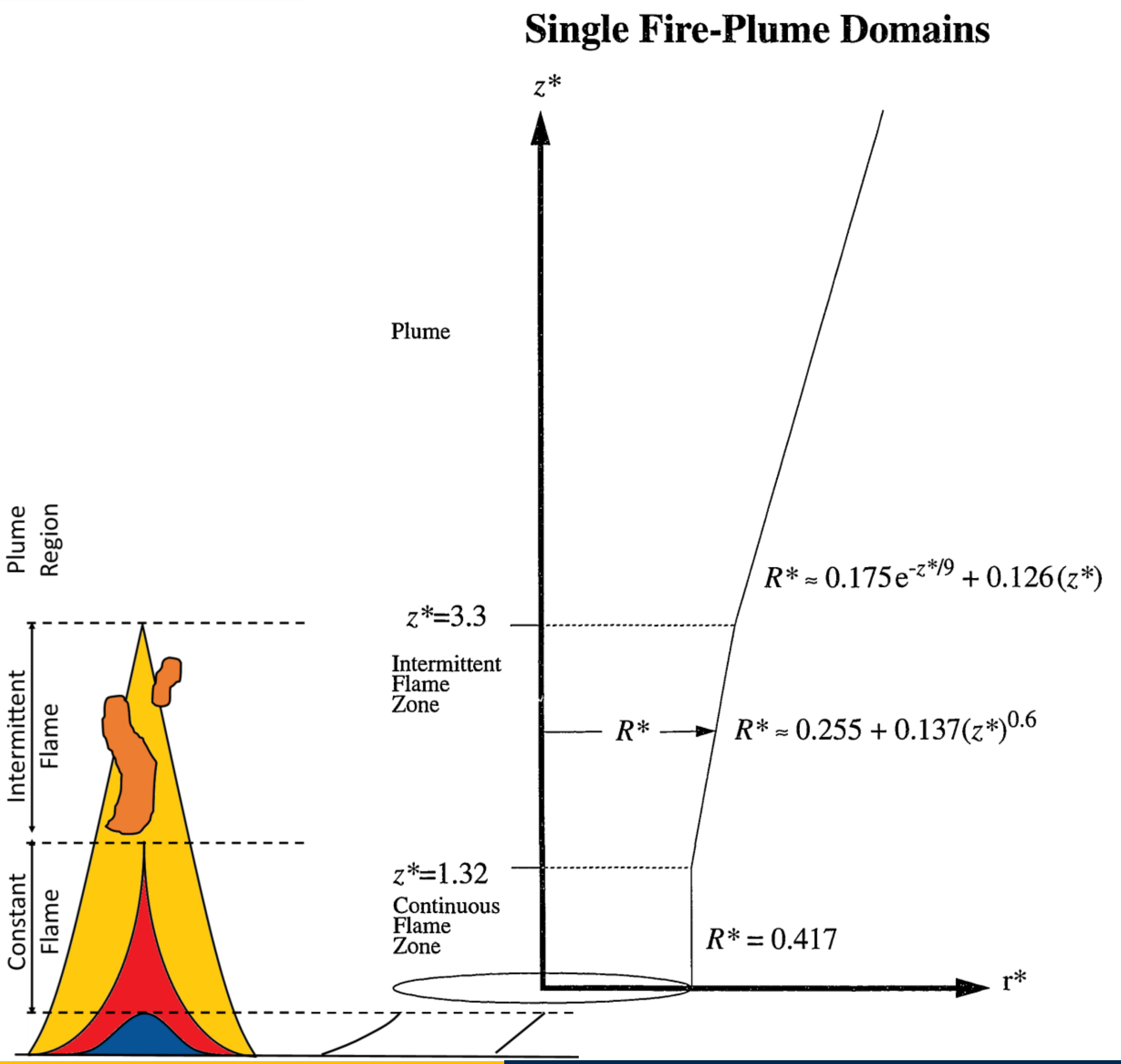
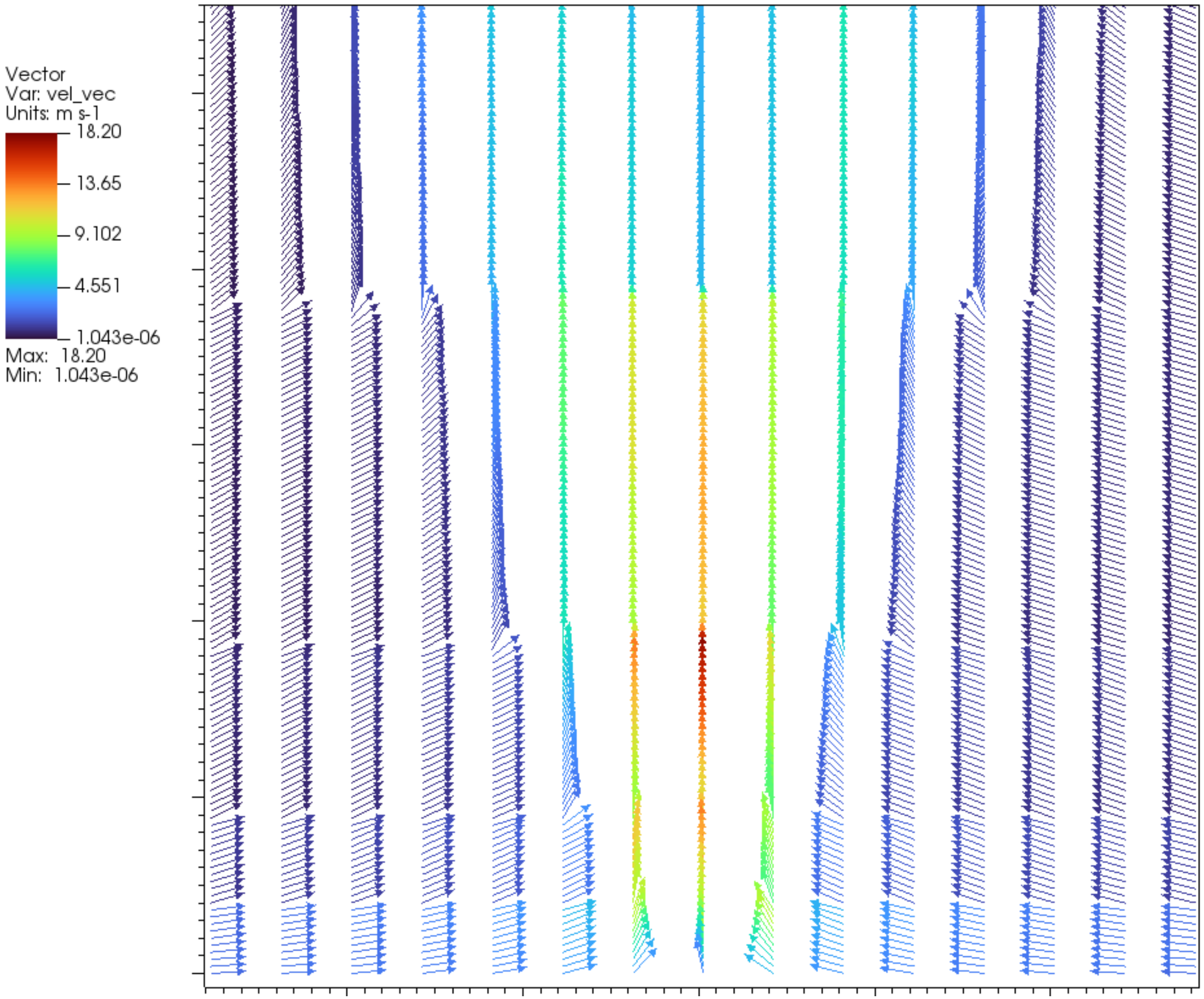


Figure: Empirical centerline temperature and velocity, based on McCaffrey, 1983.

Buoyant Plume



Buoyant Plume



Buoyant Plume

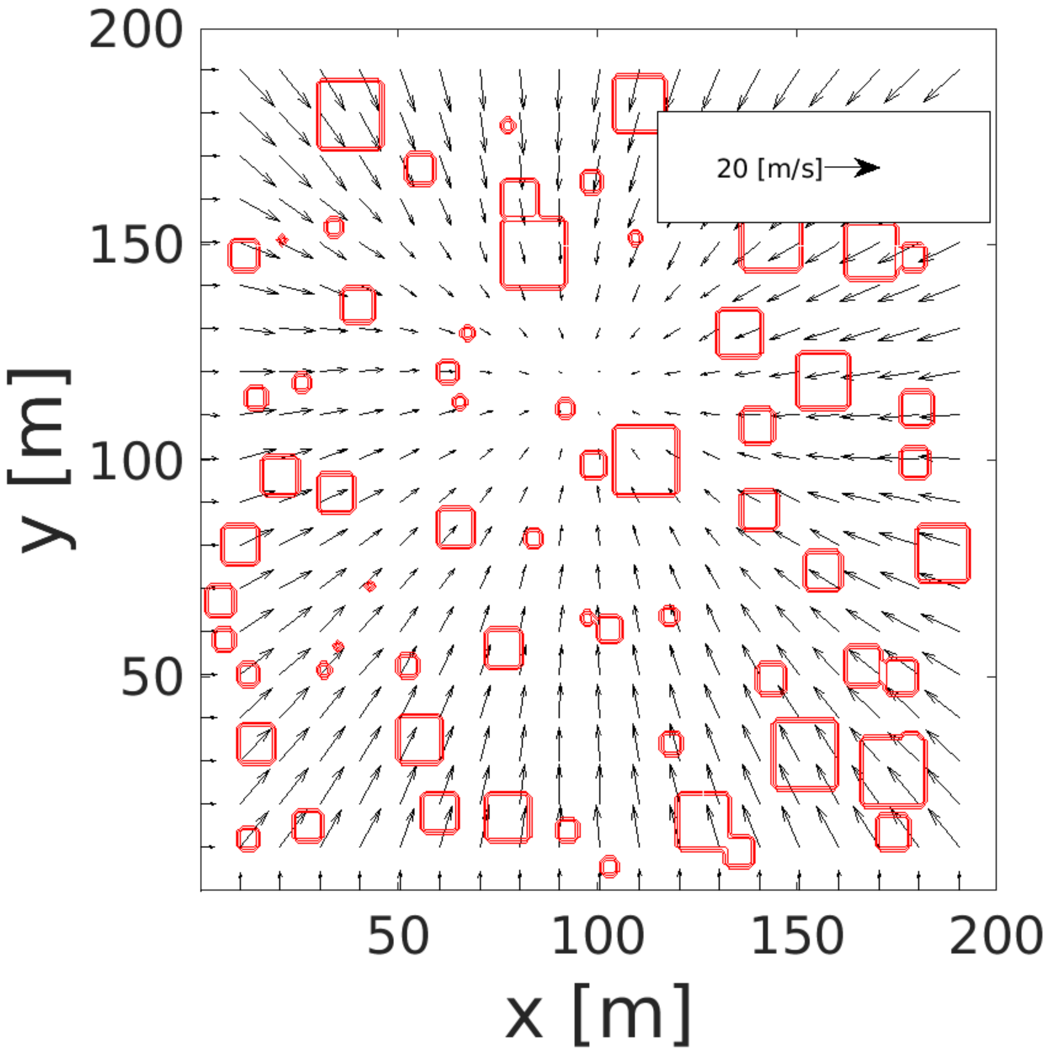
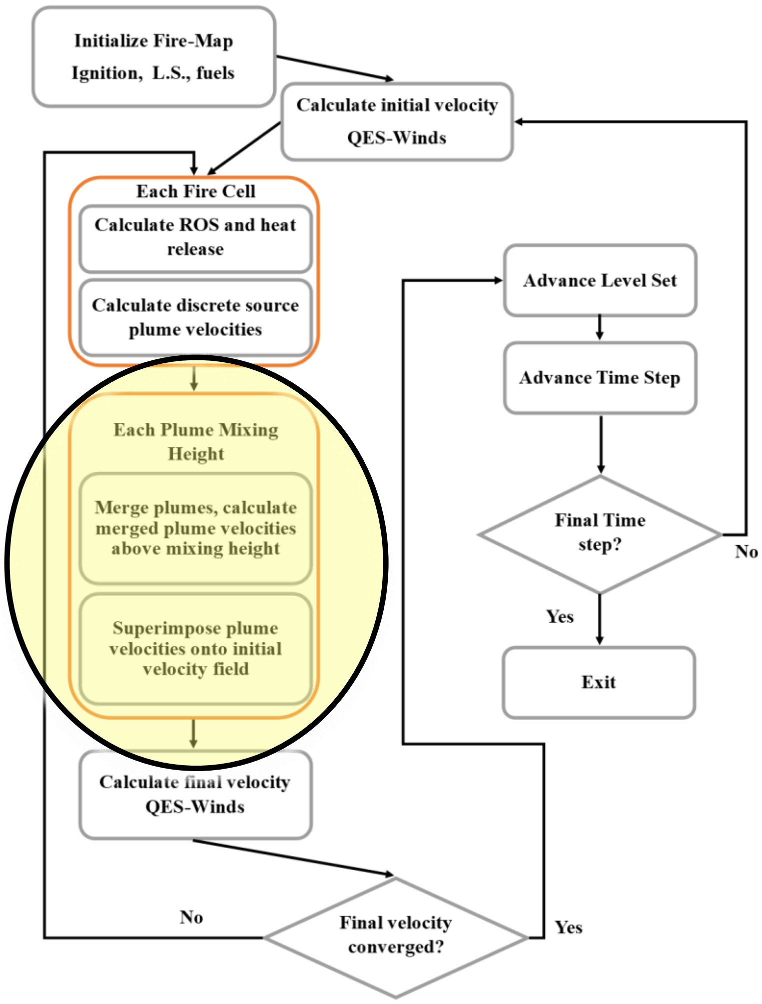


Figure: Superposition of velocity fields, each square is distinct plume source.

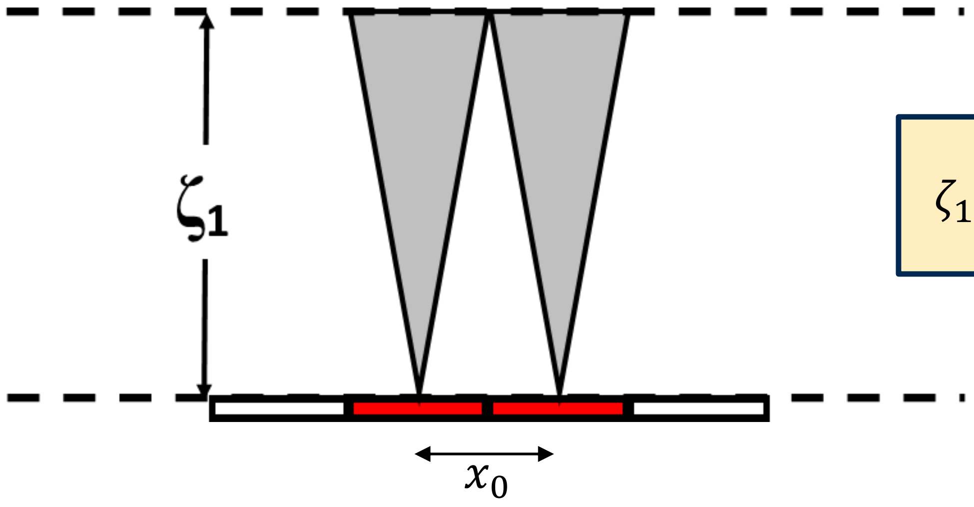
When Plumes Merge?

Bogus Creek Fire, Yukon Delta National Wildlife Refuge in southwest Alaska. - Matt Snyder

QES-Fire Overview



Merging Plume



$$\zeta_1 = \mu_m x_0 \quad (3)$$

Figure: Merging height with no mutual entrainment.

Merging Plume

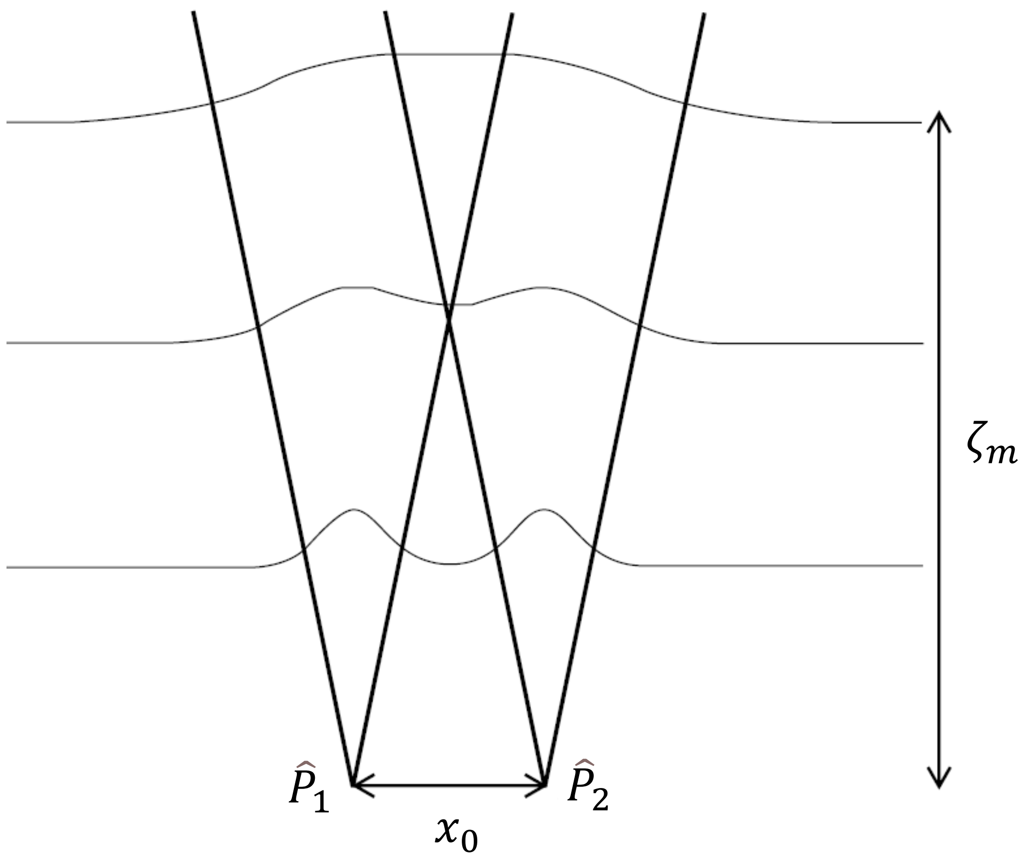
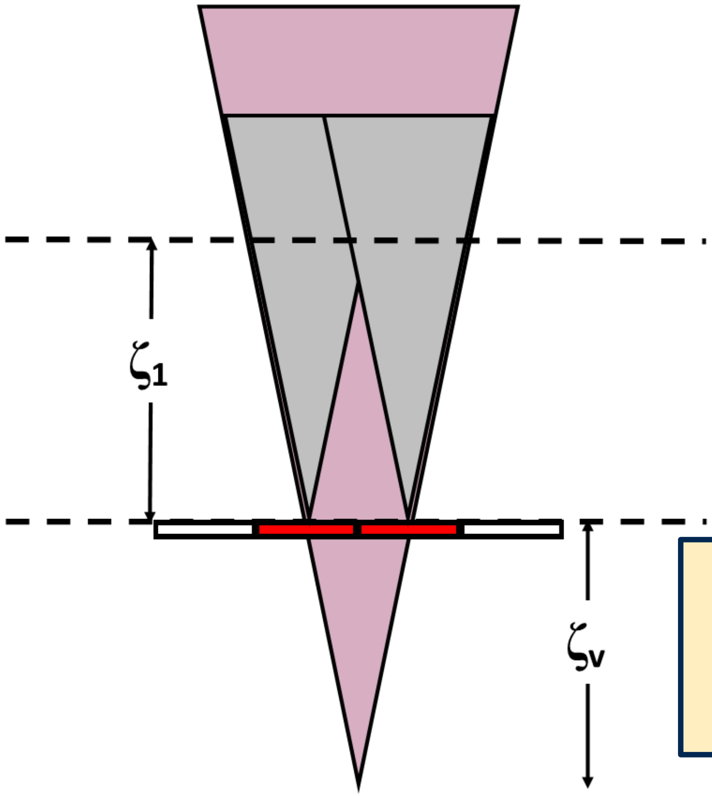


Figure: Schematic of two axisymmetric coalescing turbulent plumes. [Kaye and Linden, 2004]

Merging Plume



$$\mu_m = f(\mathrm{R}, x_0) \quad (4)$$

$$\zeta_v = 0.91\sqrt{2}\mu_m x_0 - \mu_m x_0 \quad (5)$$

Figure: Turbulent plume merging with entrainment.

Merging Plume

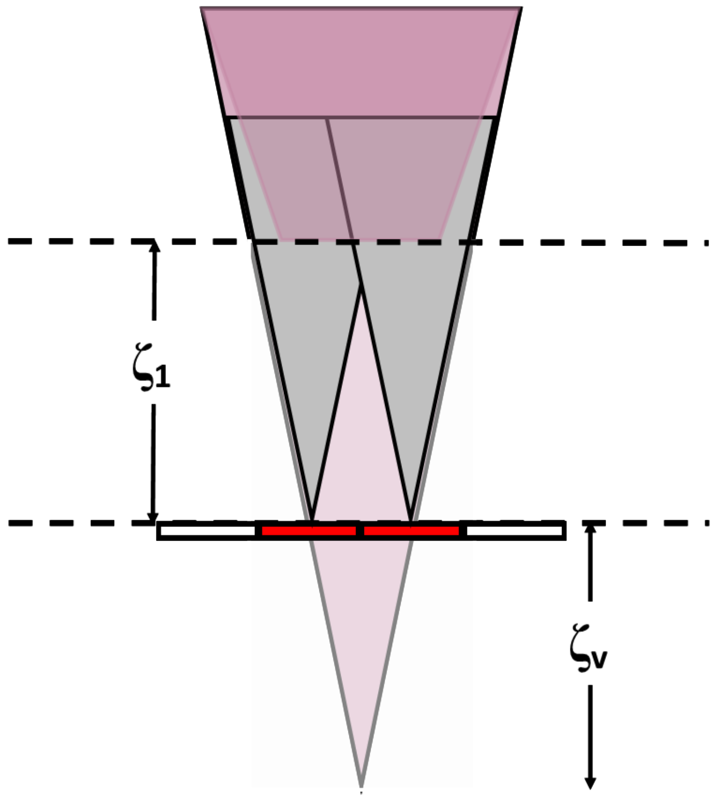
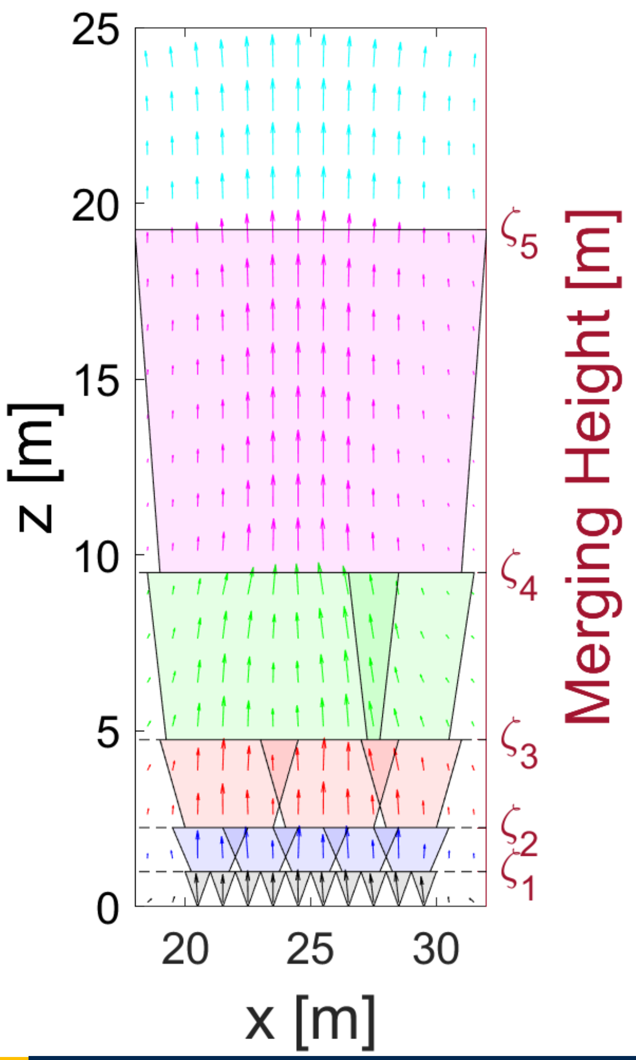


Figure: Application of filter for merging plumes.

Merging Plume

Figure: Schematic of merging plumes in QES-Fire.



Merging Plume

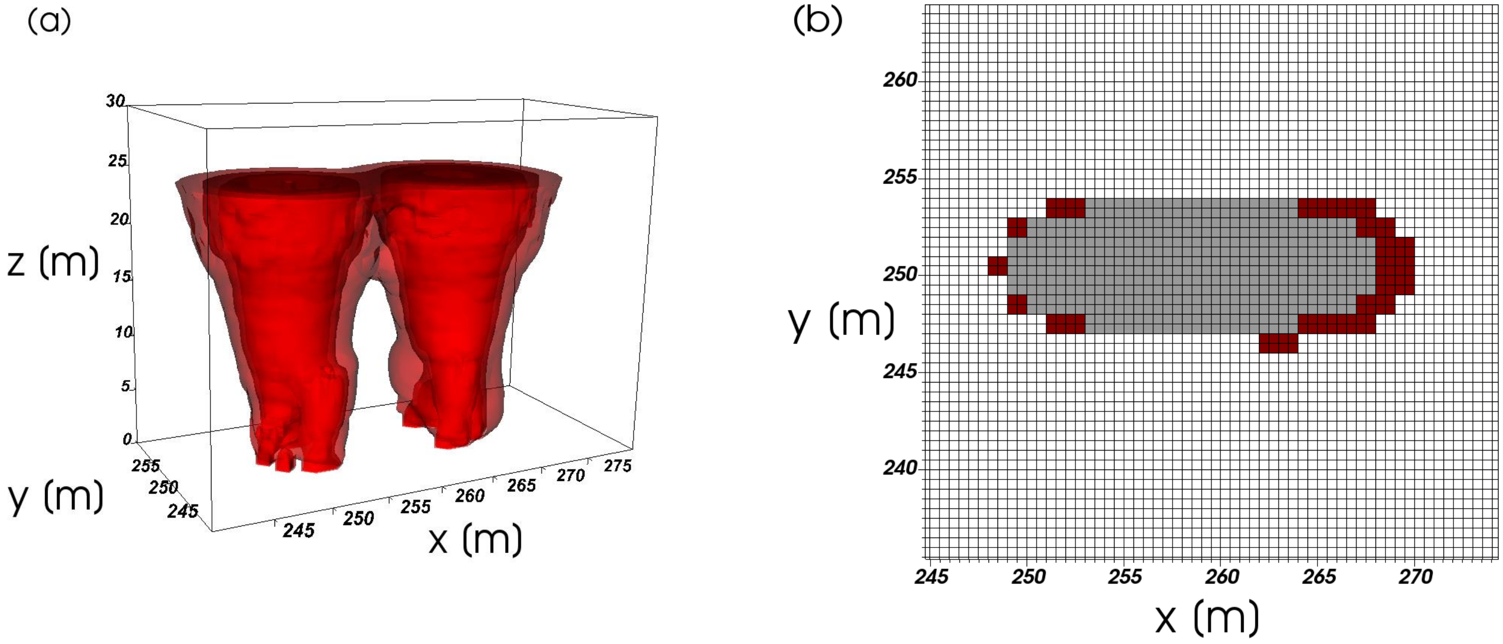


Figure: Heat release per fully burning grid cell is 2.1 kW/m^3 with a maximum vertical velocity of 5.4 m/s. Cell dimensions are 1 m x 1 m x 0.25 m. Background winds are 5 m/s along the positive x-axis.

Unequal Plumes - Fuel

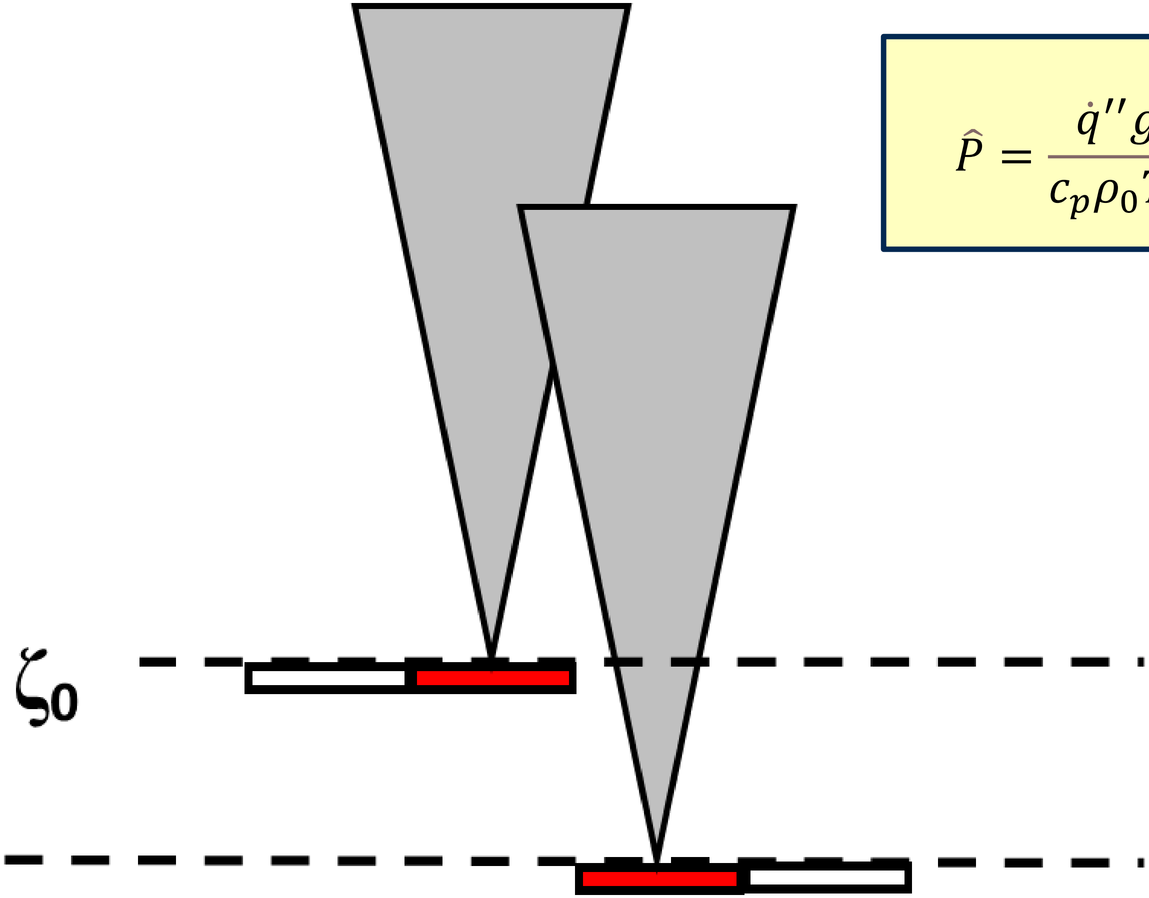
Figure: August Complex Fire - Mike McMillan/USFS

Figure: August Complex Fire - IncïWeb

Unequal Plumes - Terrain

Figure: River Fire - AP Photo/Noah Berger

Merging Unequal Plumes



$$\hat{P} = \frac{\dot{q}''g}{c_p\rho_0 T_0} \qquad (6)$$

Figure: Theoretical plume rise model at discrete sources.

Merging Unequal Plumes

$$\dot{q}'' = -\nu \frac{\Delta T}{\delta z} \qquad (7)$$

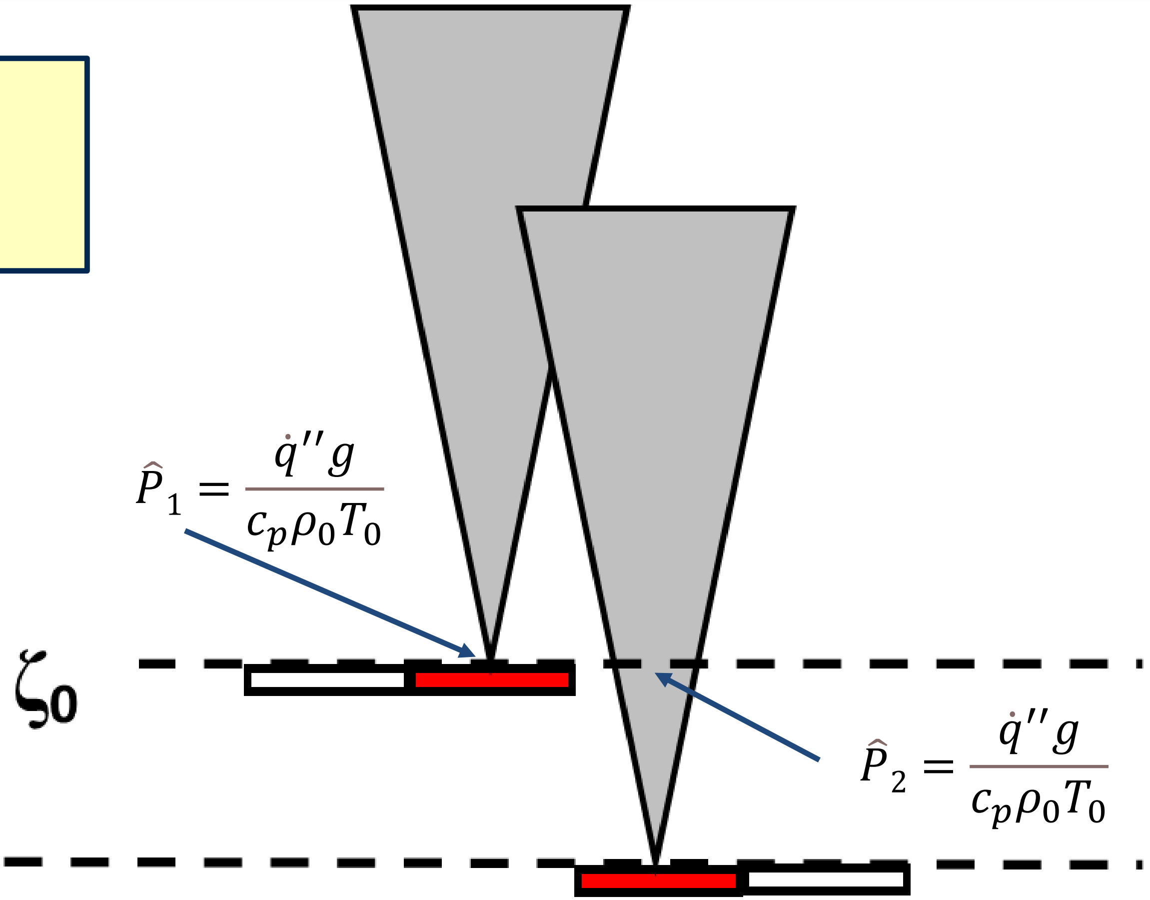


Figure: Theoretical plume rise model at discrete sources.

Merging Unequal Plumes

$$\kappa = \frac{\hat{P}_2}{\hat{P}_1} = \frac{\Delta T_2/\Delta\zeta_2}{\Delta T_1/\Delta\zeta_1} \qquad (8)$$

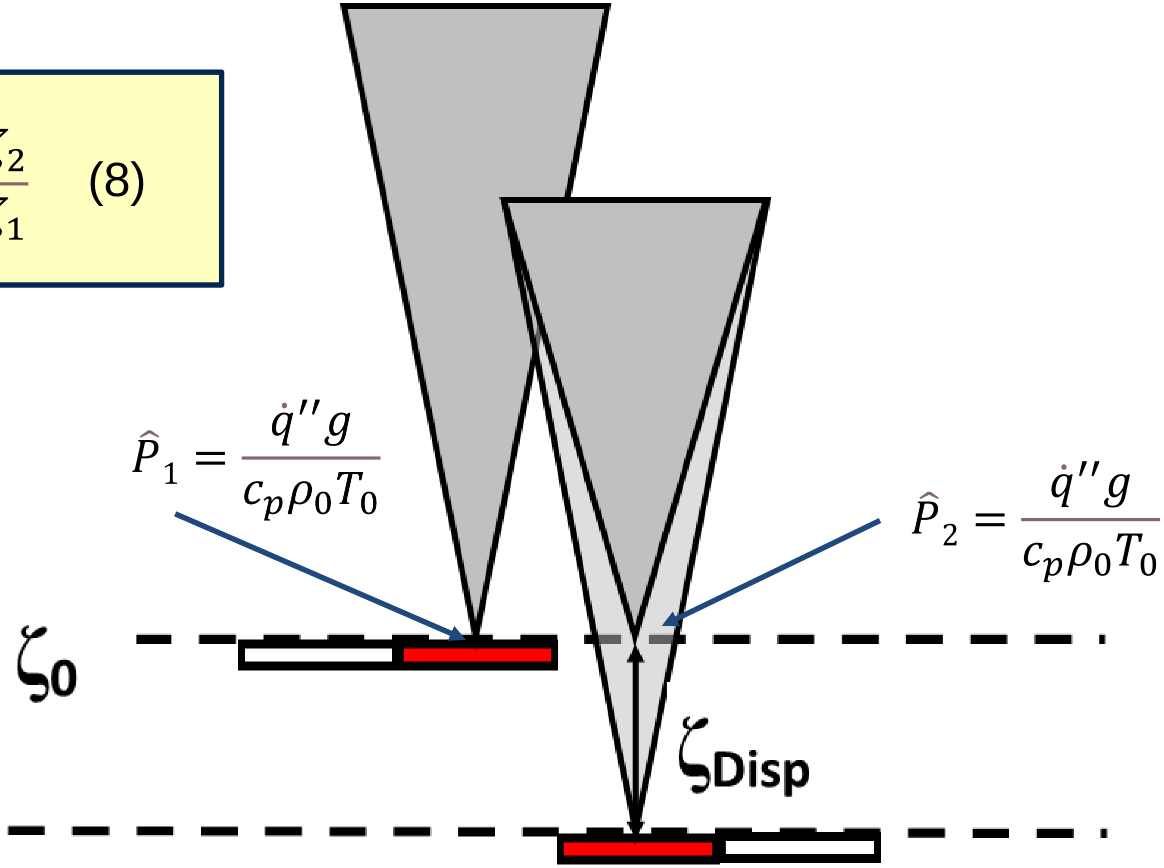
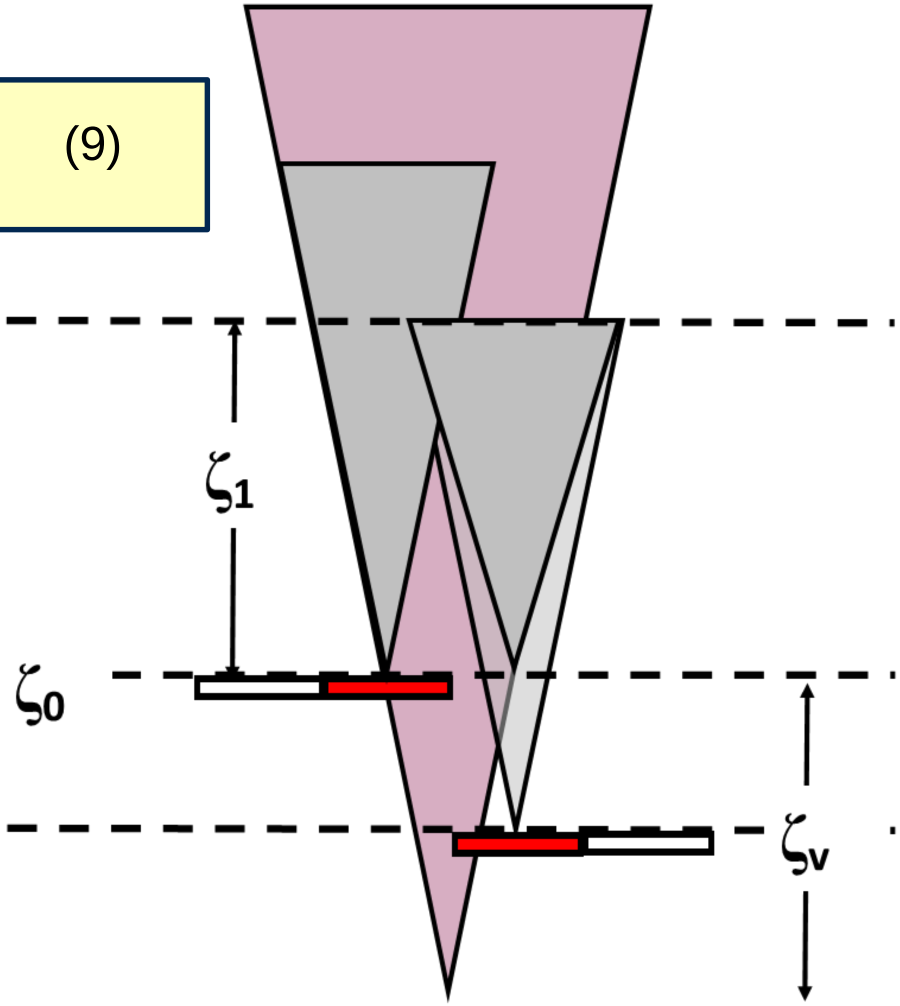


Figure: Lowest elevation plume buoyancy calculated at ζ_0 and plume is displaced (ζ_{Disp}).

Merging Unequal Plumes

$$\mu_m = f(\mathrm{R}, x_0, \kappa) \qquad (9)$$



Merging Unequal Plumes

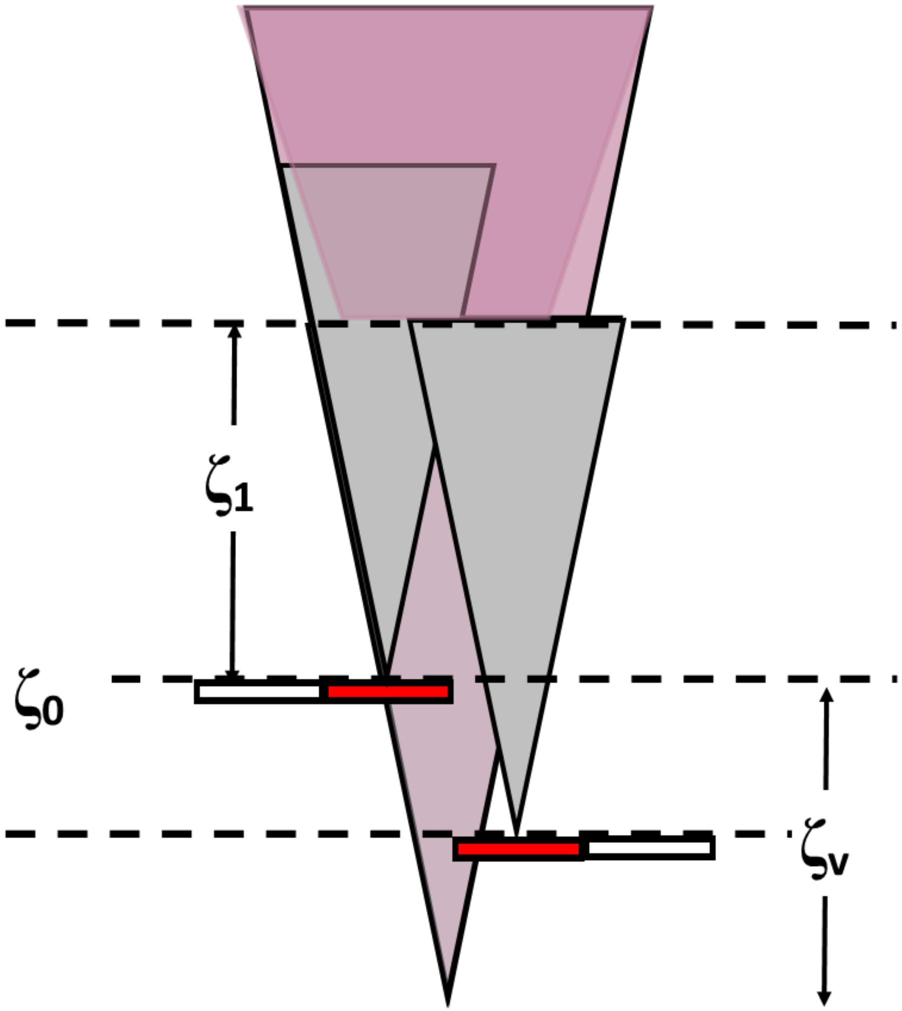


Figure: Parameterizations applied for velocity field.

2012 RxCadre L2F Simulation

Modeled the RxCadre 2012 L2F burn [Ottmer et. al., 2016] in QES-Fire.

Forested non-homogeneous burn conducted at Eglin Air Force base

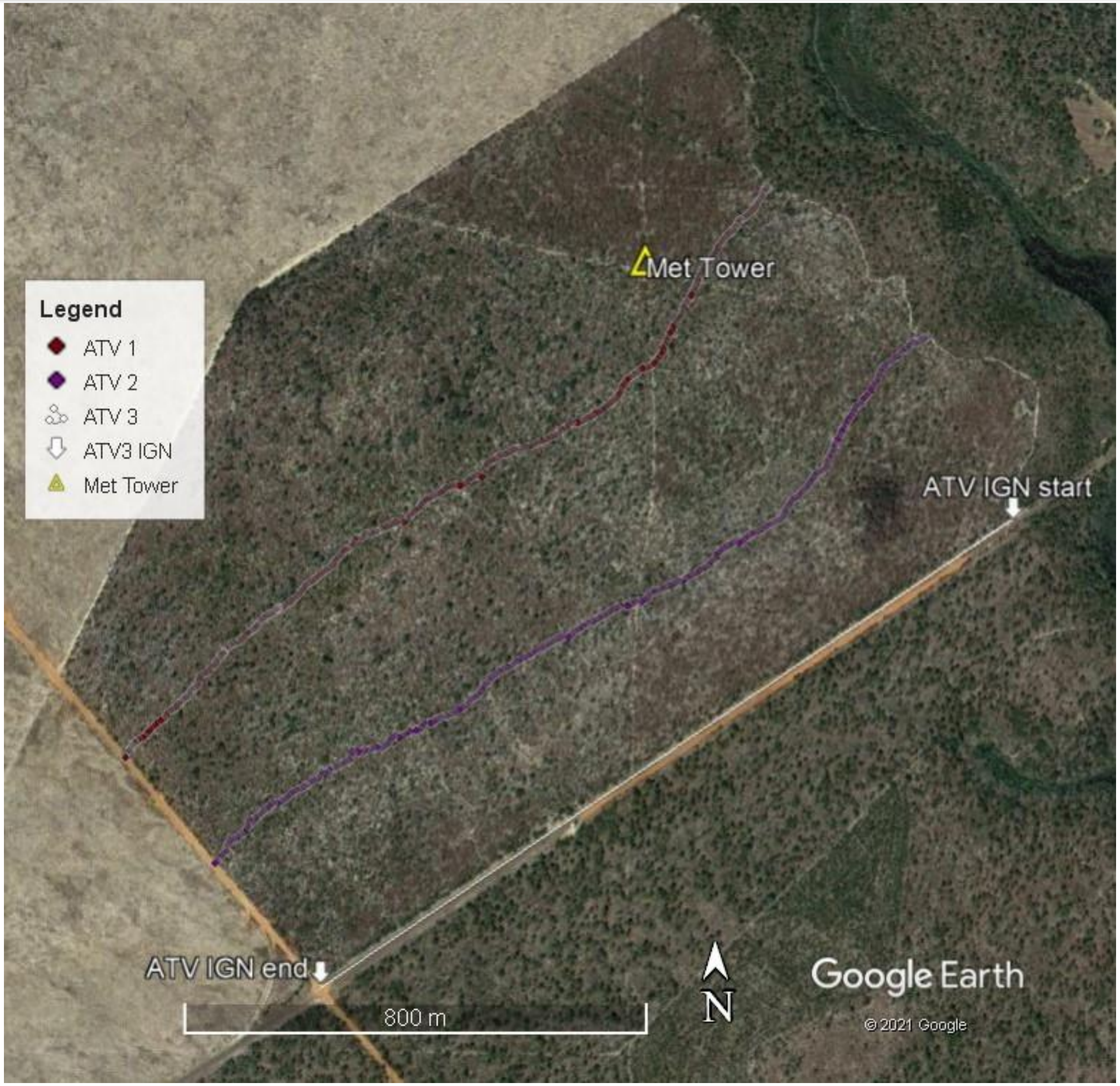
- Previously modeled homogeneous burn for FireFlux II [Clements et.al., 2014]

- Fuel type: LANDFIRE 2012 Database
- Ground fuel moisture: 14%
- Fuel depth: 0.4 m
- Fuel load: 0.96 kg/m^2
- Winds: 3 m/s at height of 9 m and 130^o
- Fire ignition tracked visually from aerial infrared, updated each QES-Fire time step

2012 RxCadre L2F Simulation

Figure: L2F burn, Eglin Air Force Base, FL, 2012.

2012 RxCadre L2F Simulation



2012 RxCadre L2F Simulation

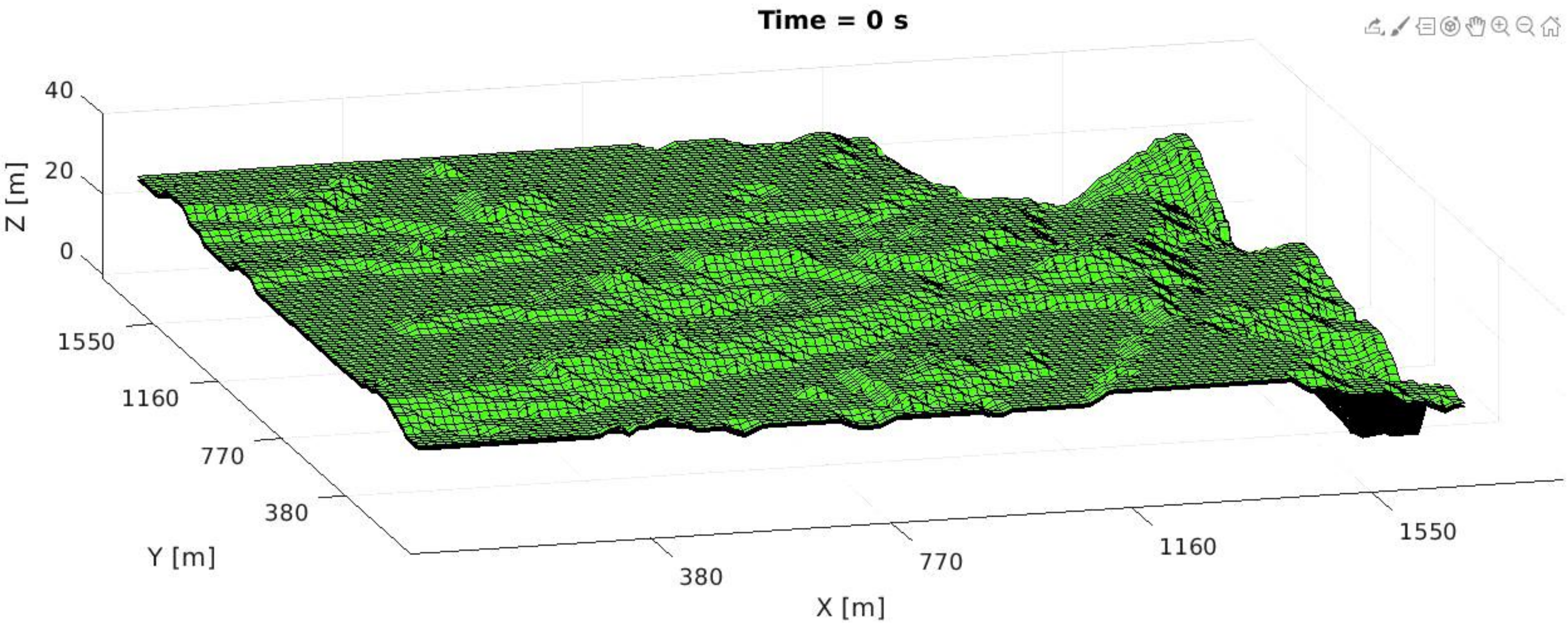


Figure: QES-Fire simulation of 2012 L2F burn.

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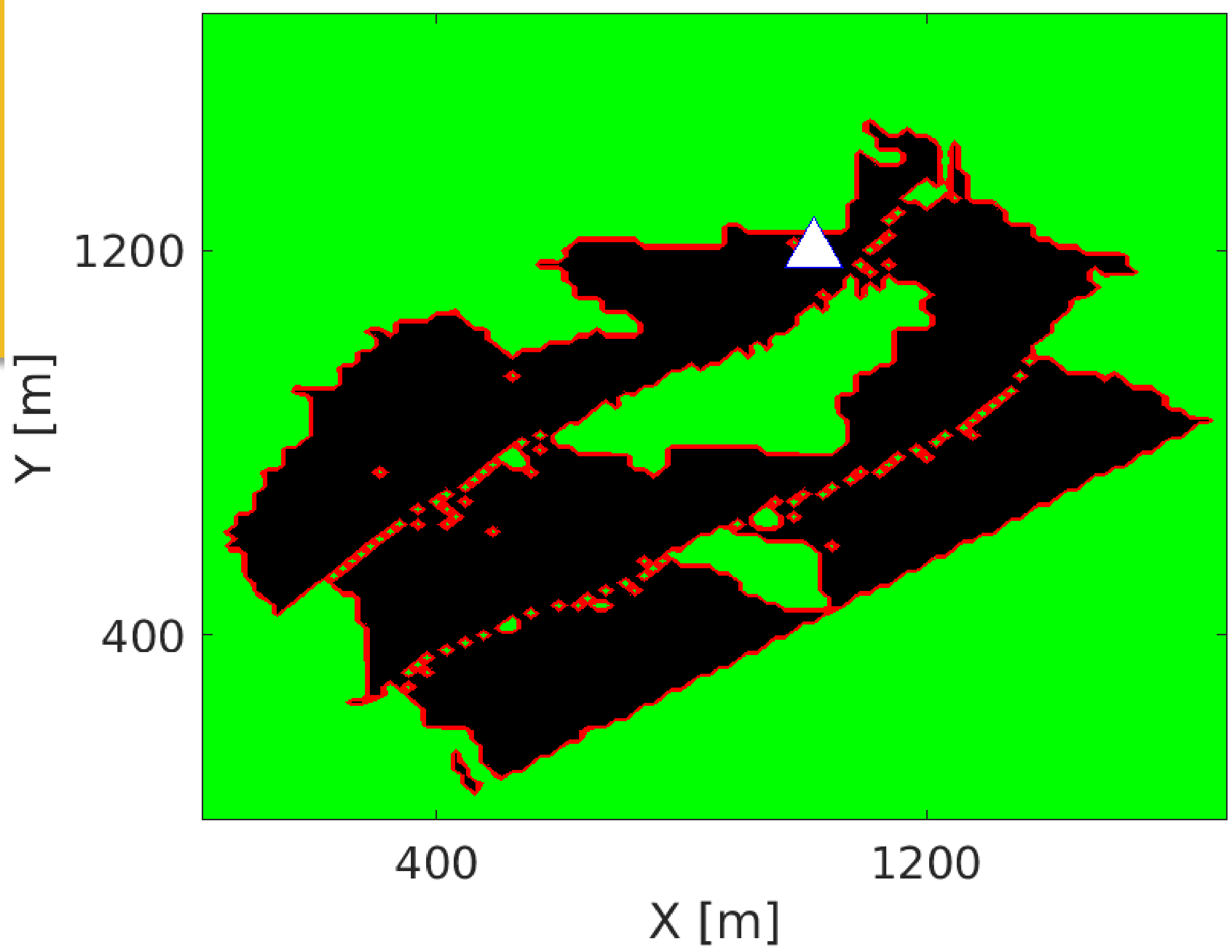
2012 RxCadre L2F Simulation

Figure: Burn perimeter calculated by QES-Fire at 18:40 UTC. Meteorological tower location shown for comparisons.



Vertical Winds: 3.8 m

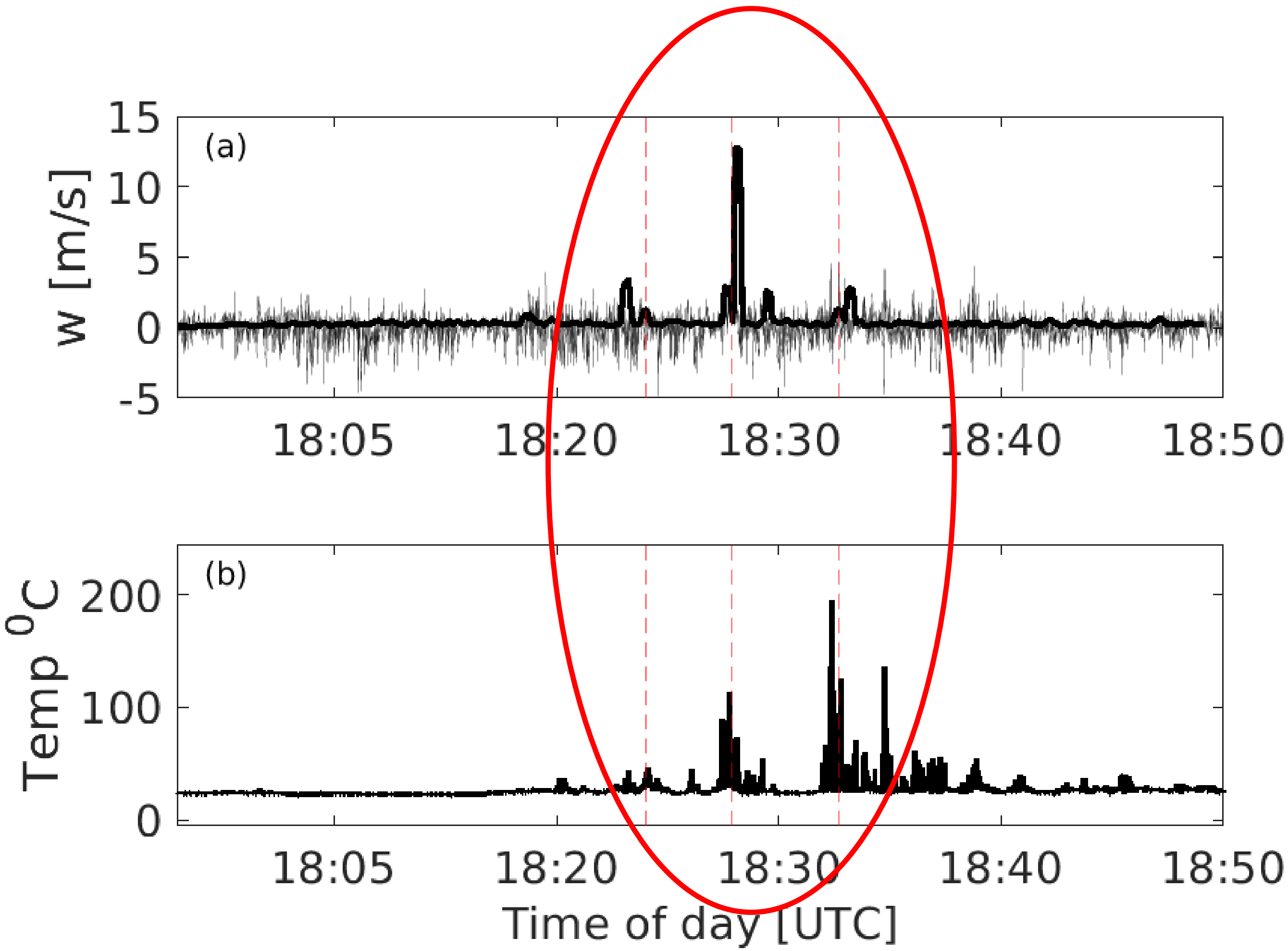


Figure: Tower, 3.8 m height:
(a) Calculated vertical velocity from QES-Fire
(b) Temperature from tower

Vertical Winds: 8.7 m

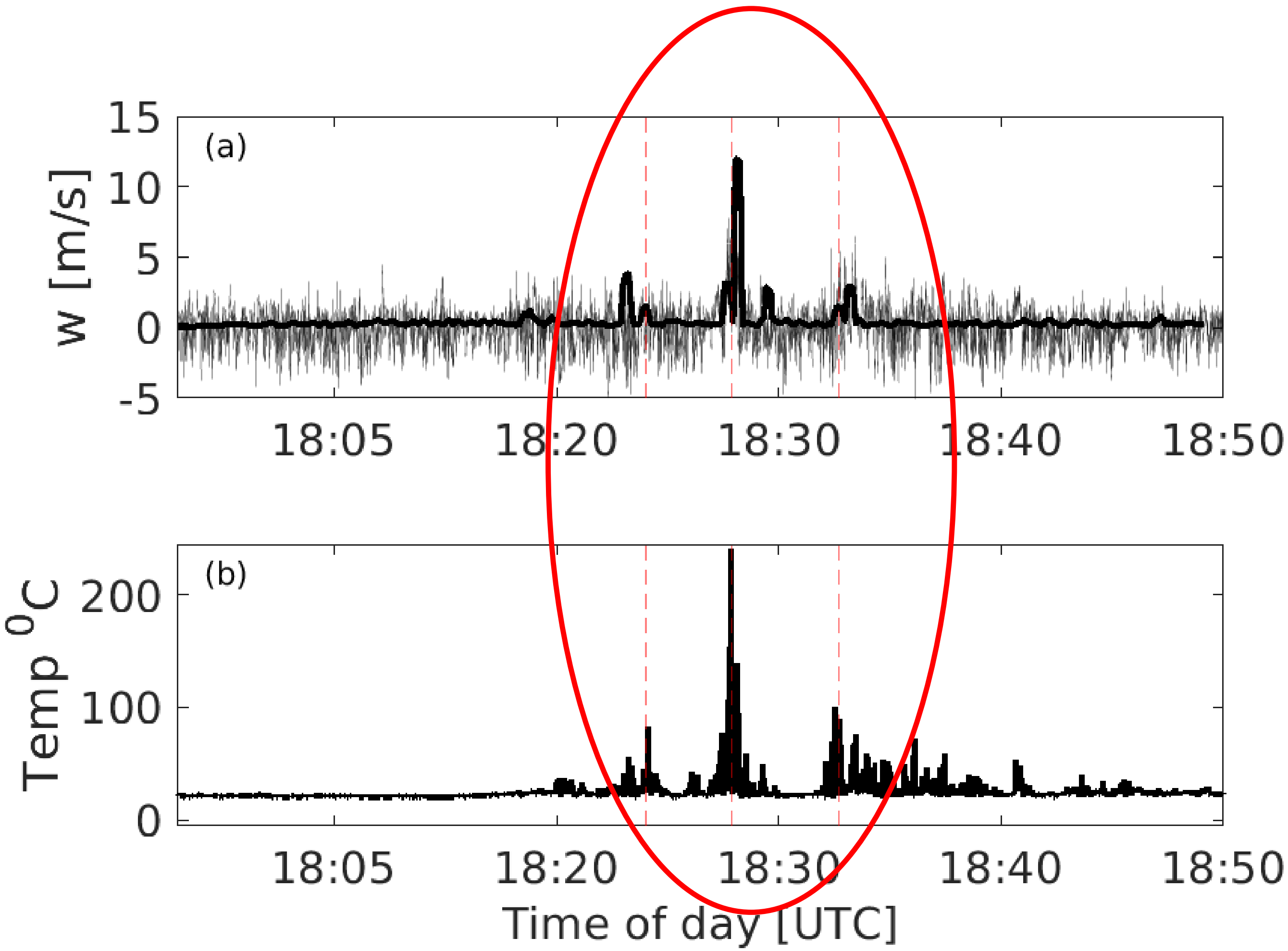


Figure: Tower, 8.7 m height:
(a) Calculated vertical velocity from QES-Fire
(b) Temperature from tower

Parameterize in the WUI?

Photo: Rocky fire in Lower Lake, CA. [Justin Sullivan, 2015]

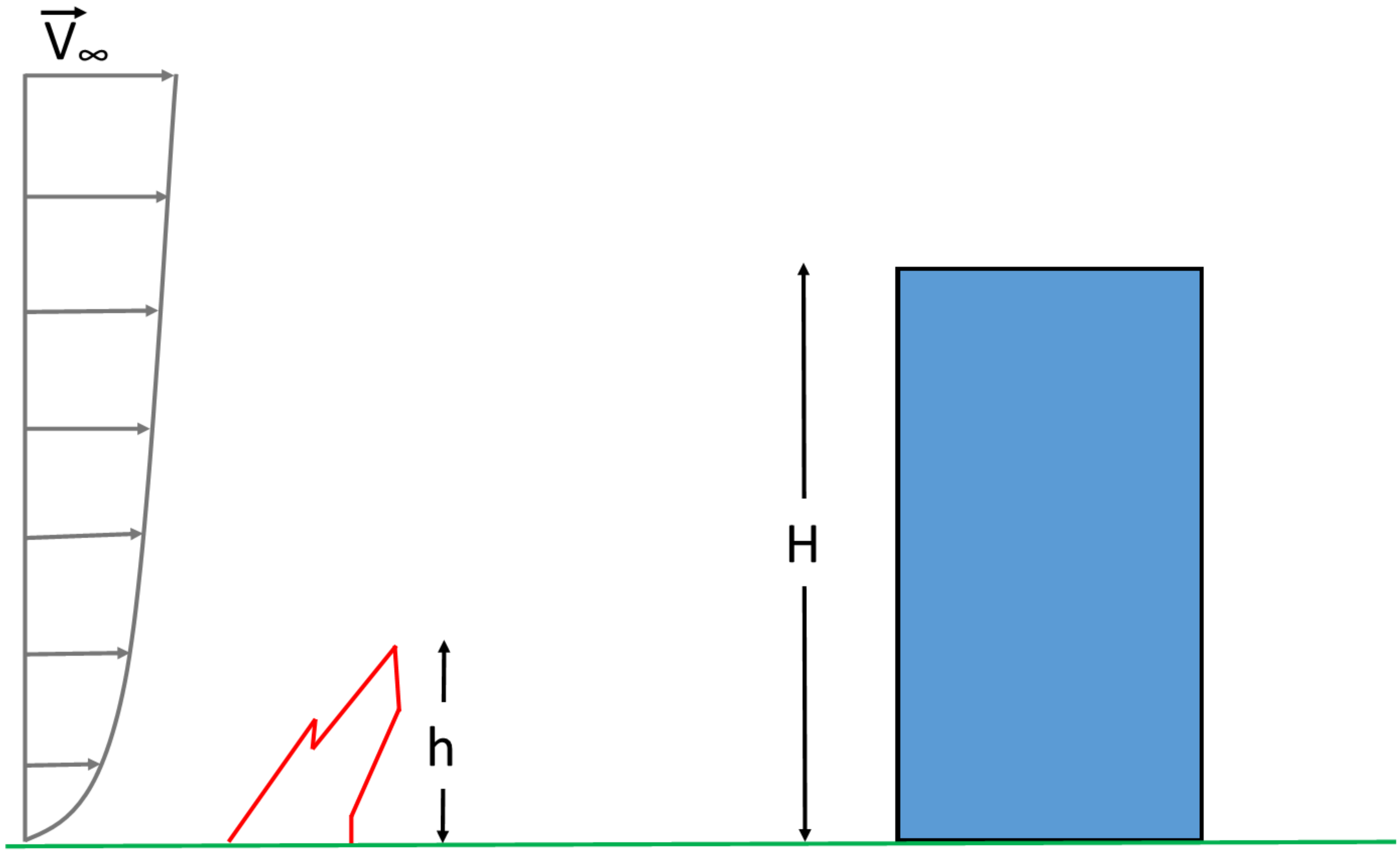
Parameterize in the WUI?

Photo: Cle Elum, WA. [Elaine Thompson, 2012]

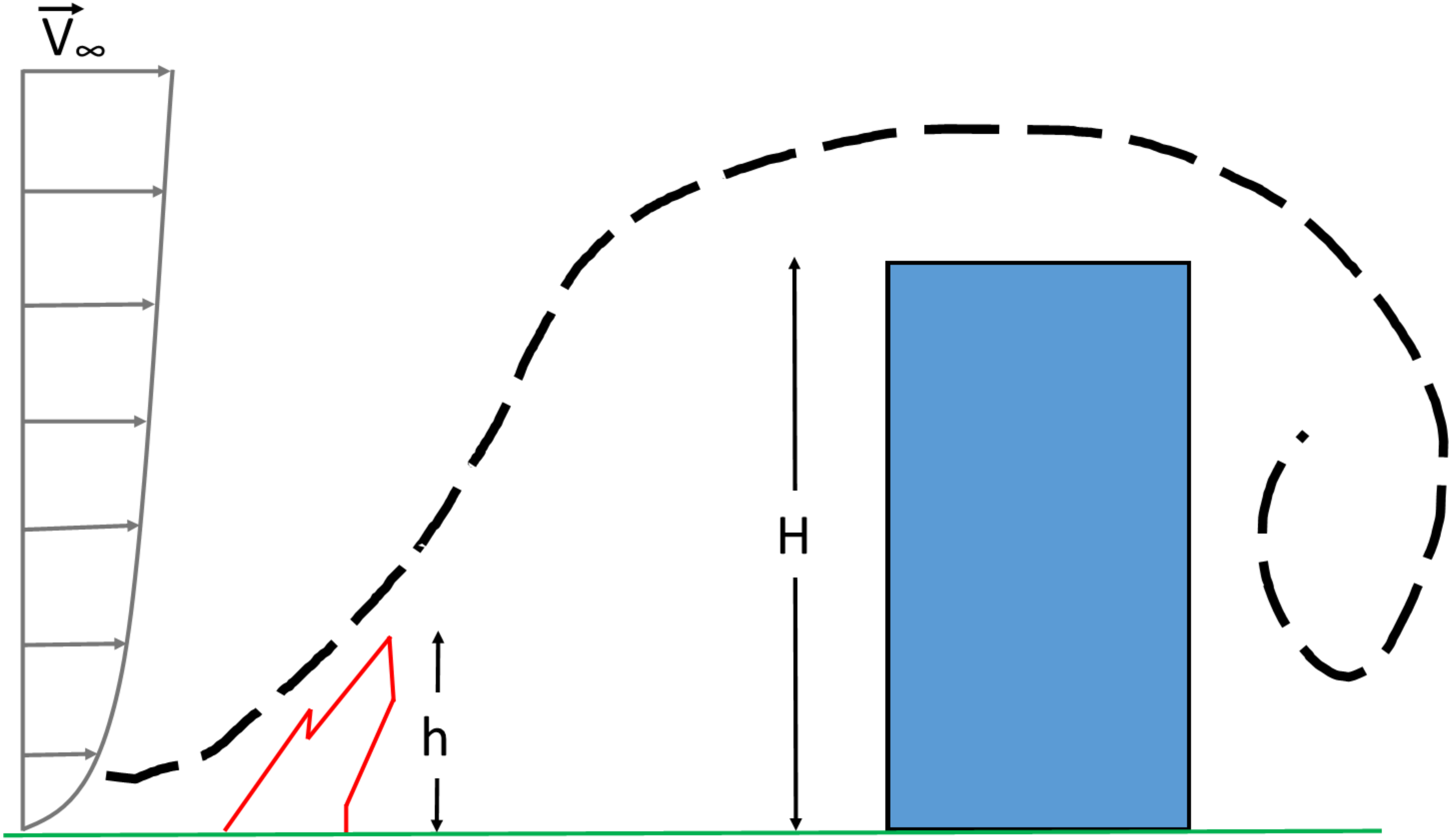
Parameterize in the WUI?

Photo: Fireworks sparked Traverse fire at Lehi, UT. [Justin Reeves, 2020]

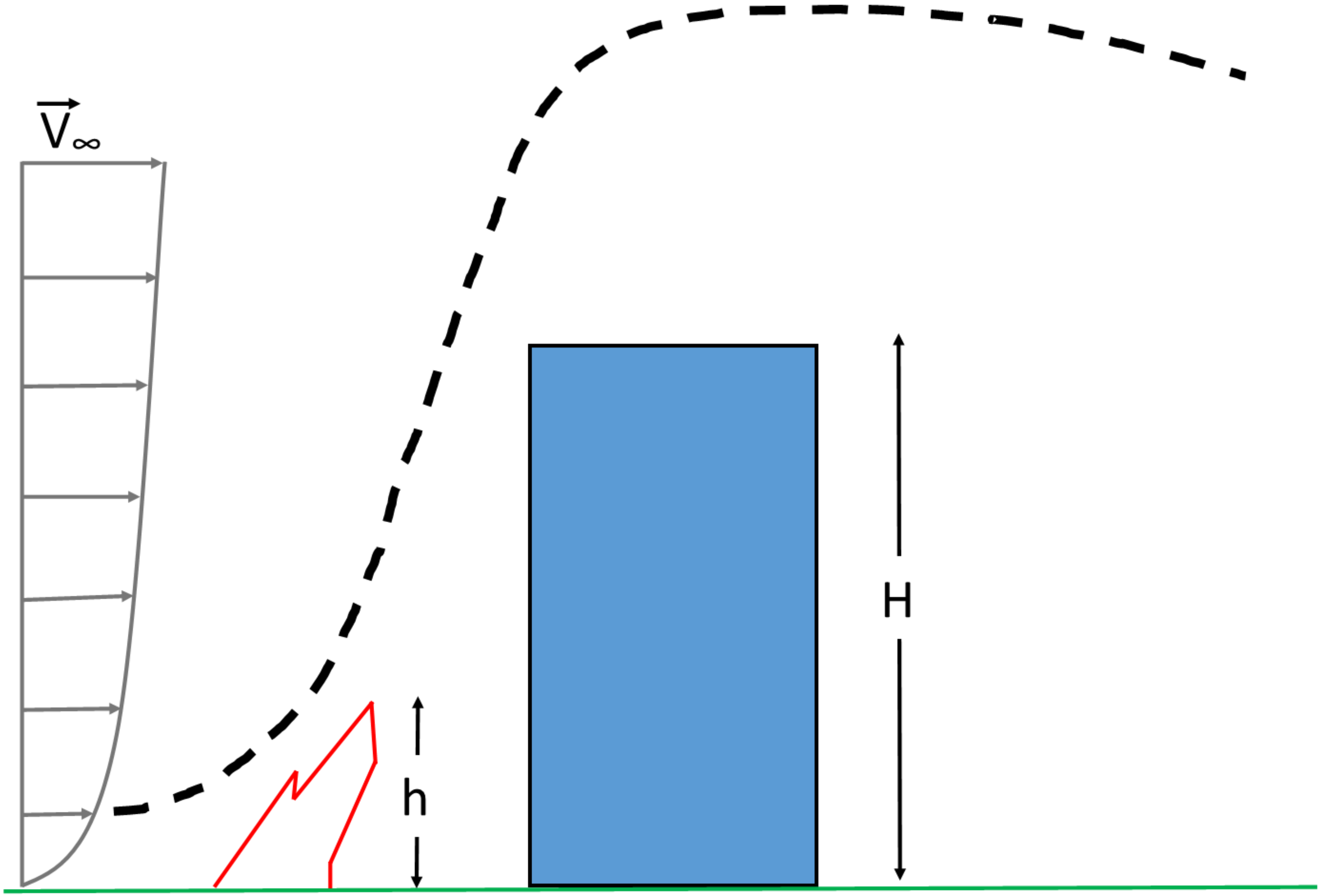
Fire-induced winds vs. momentum



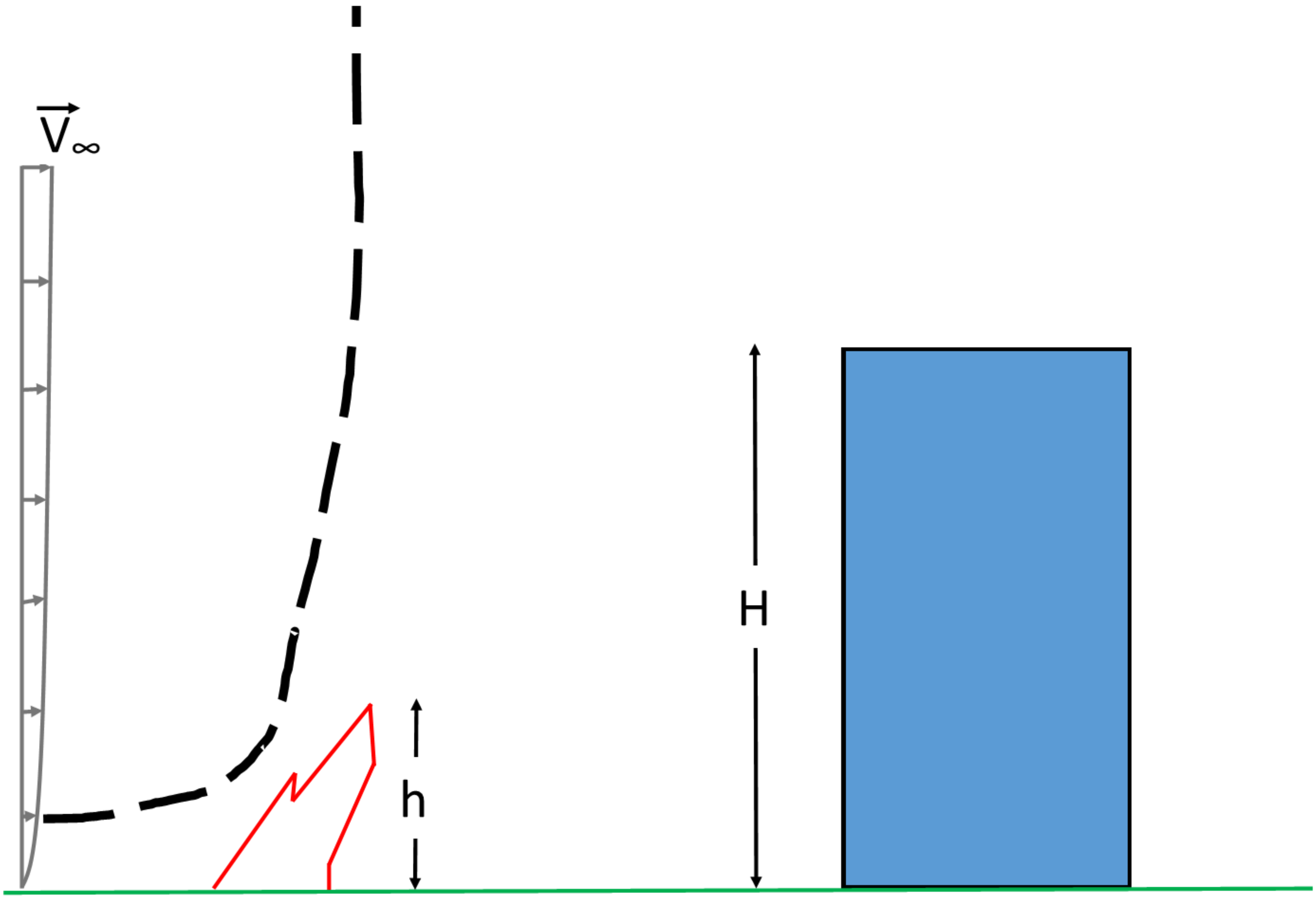
Fire-induced winds vs. momentum



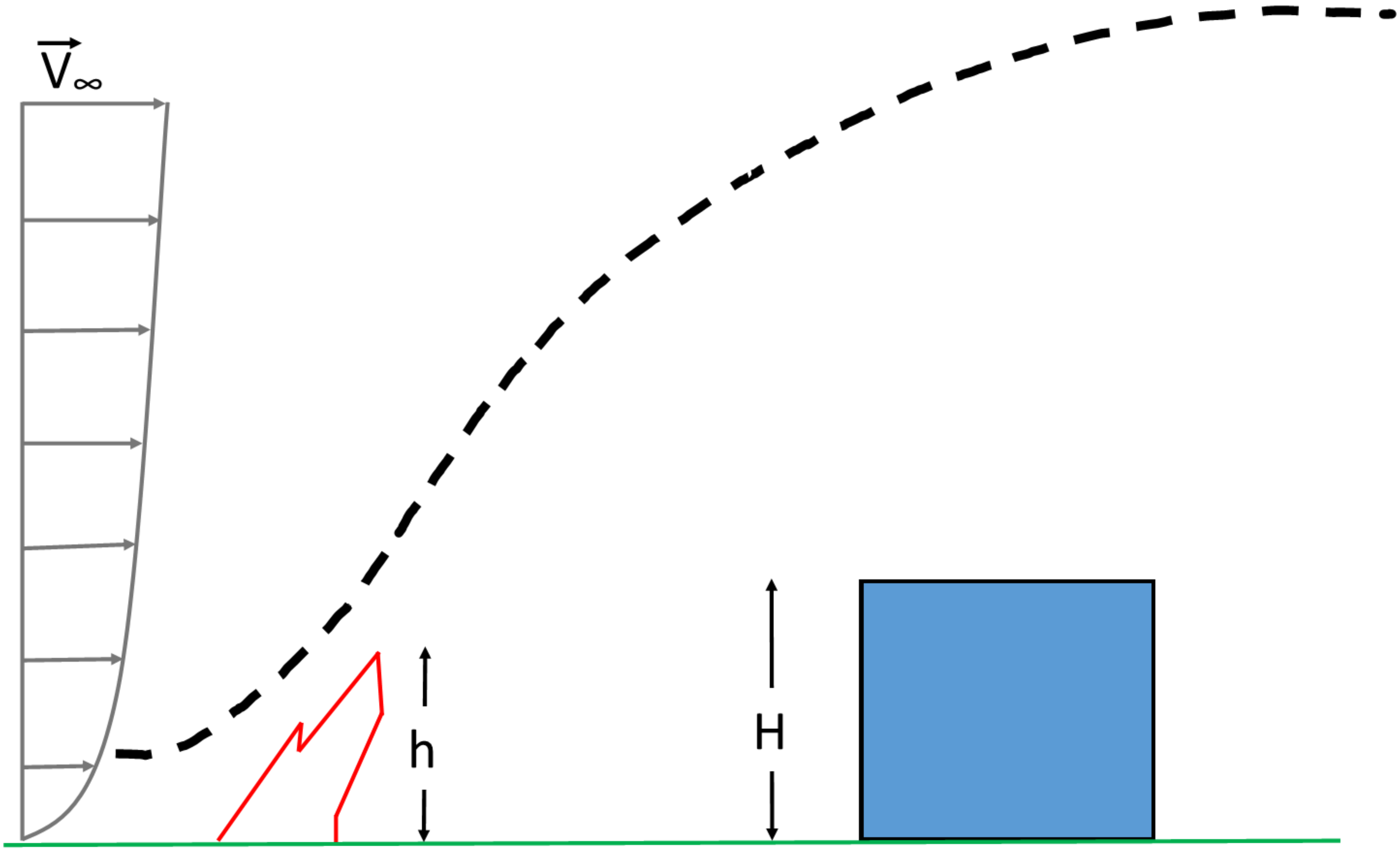
Fire-induced winds vs. momentum



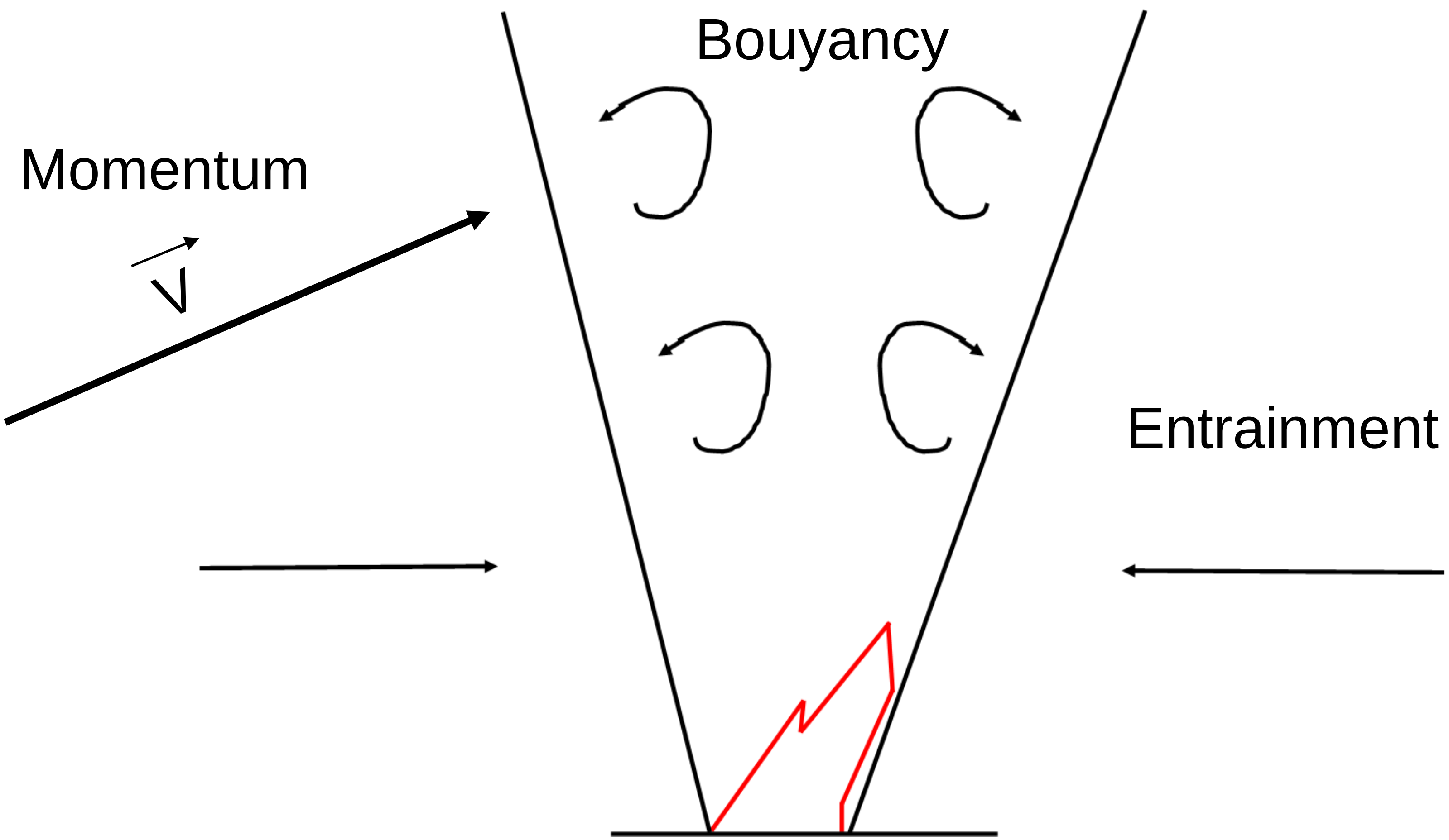
Fire-induced winds vs. momentum



Fire-induced winds vs. momentum



Fire-induced winds vs. momentum



Fire-induced winds vs. momentum

$$\frac{\text{Buoyancy Forces}}{\text{Shear Forces}}$$

Fire-induced winds vs. momentum

$$\frac{\text{Buoyancy Forces}}{\text{Shear Forces}} = \text{Richardson \#}$$

Fire-induced winds vs. momentum

$$Ri = \frac{Gr}{Re^2}$$

$$Gr = \frac{g\beta(T_{flame} - T_{air})h^3}{\nu^2}$$

$$Re = \frac{VH}{\nu}$$

Fire-induced winds vs. momentum

$$Gr = \frac{g\beta(T_{flame} - T_{air})h^3}{(VH)^2}$$

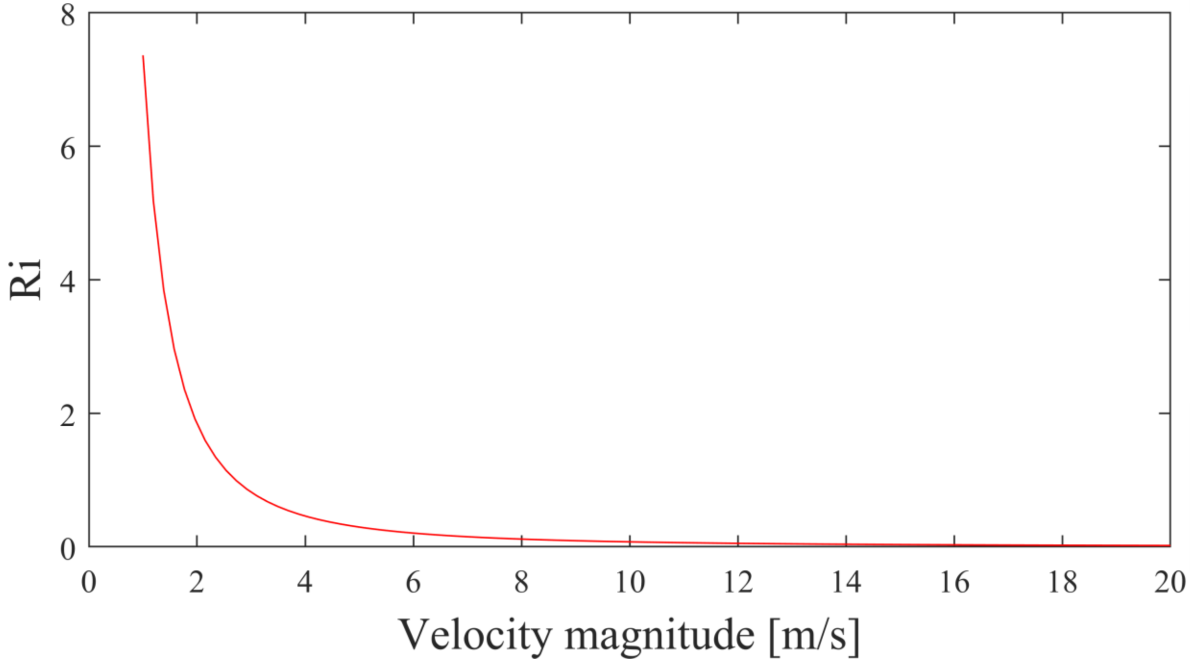


Figure: Richardson number as a function of velocity magnitude.

$Ri < 0.1$
Ignore free convection

$Ri > 10$
Ignore forced convection

$0.1 < Ri < 10$
Account for both

Fire-induced winds vs. momentum

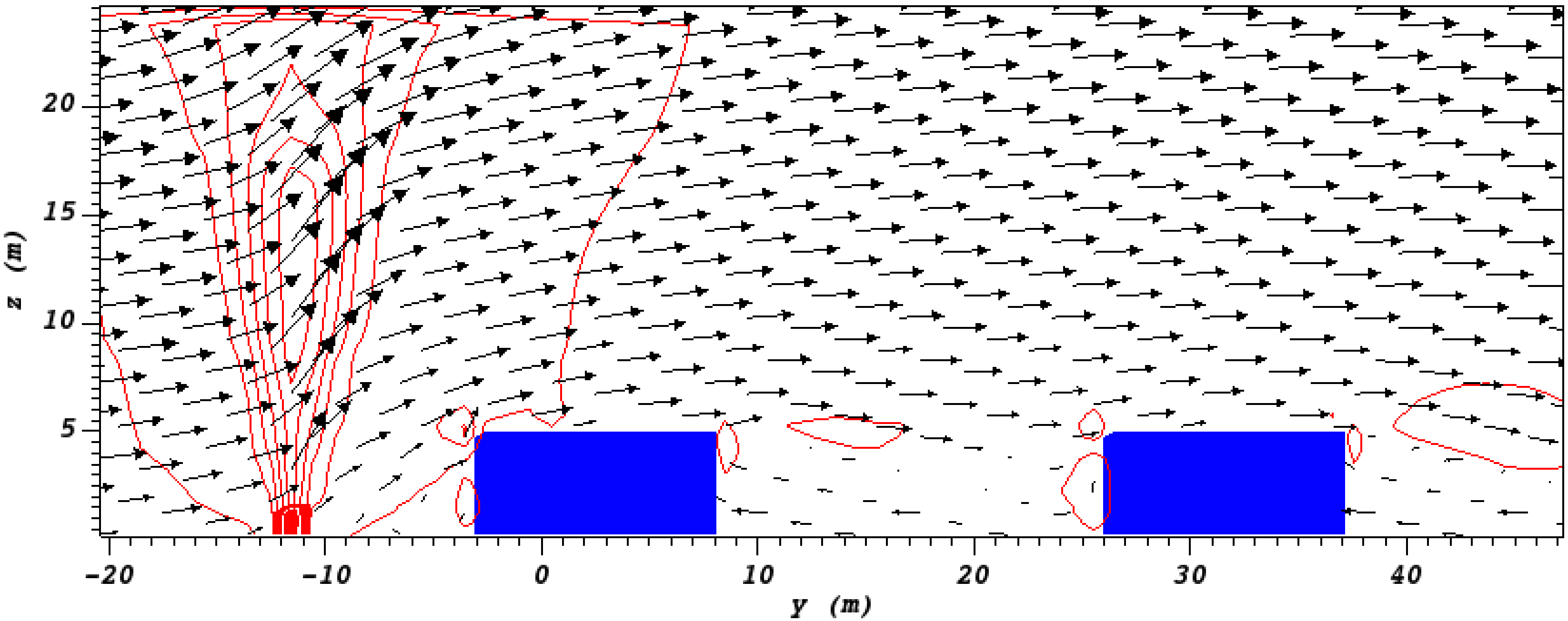


Figure: Velocity field with fire and building parameterizations. Vertical velocity contours (red).

Thank You

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