Particulate Matter Emission Factors in Southeastern U.S. Pine-grasslands

SmoC Webinar

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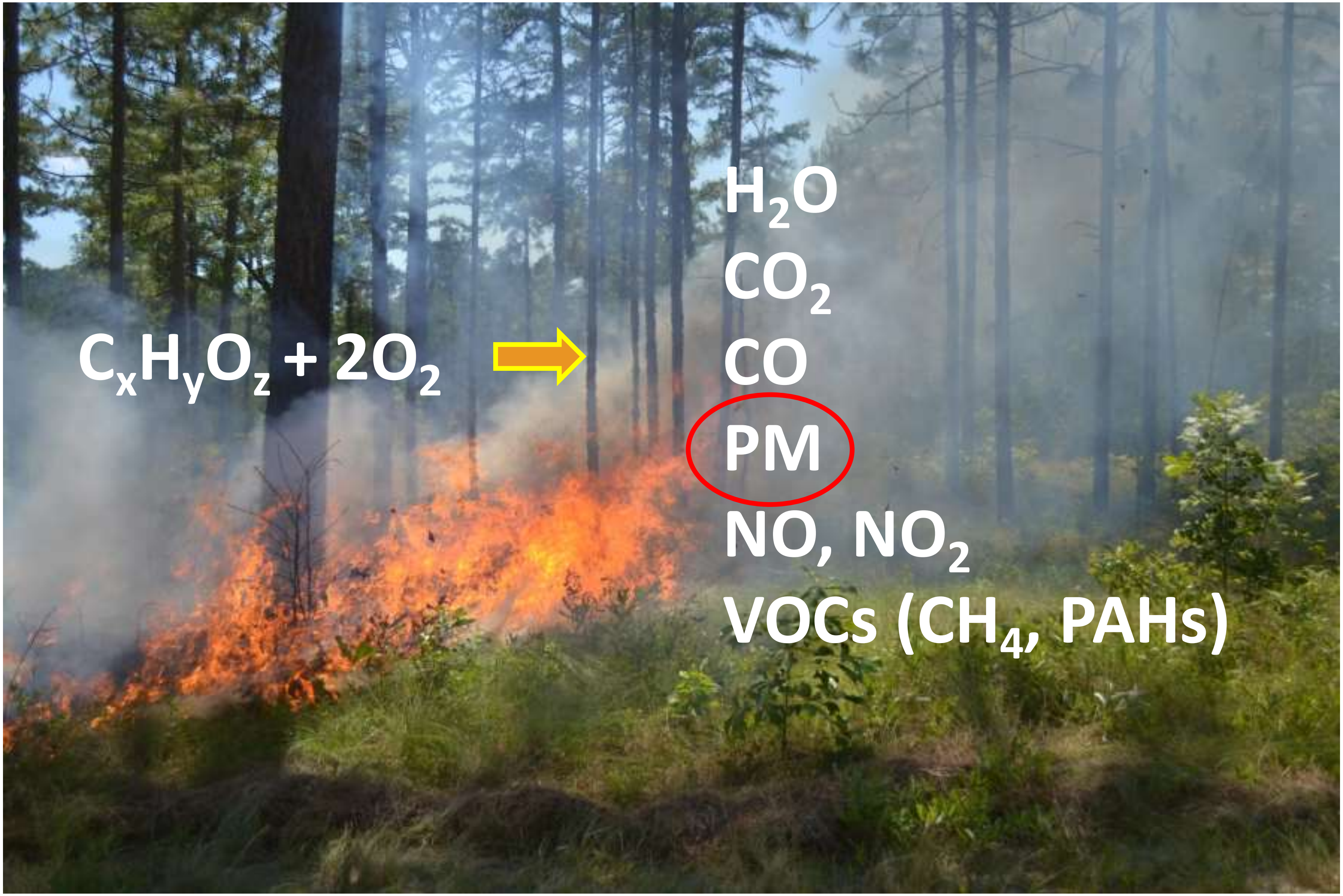

$C_xH_yO_z + 2O_2$ →
H_2O
CO_2
CO
PM
NO, NO_2
VOCs (CH_4, PAHs)


$PM_{2.5}$ Emission Factor (EF) = $PM_{2.5}$ emitted / fuel consumed

Emissions Inventories

Burned Area

Fuel Loading

Fuel Consumption

Emission Factor

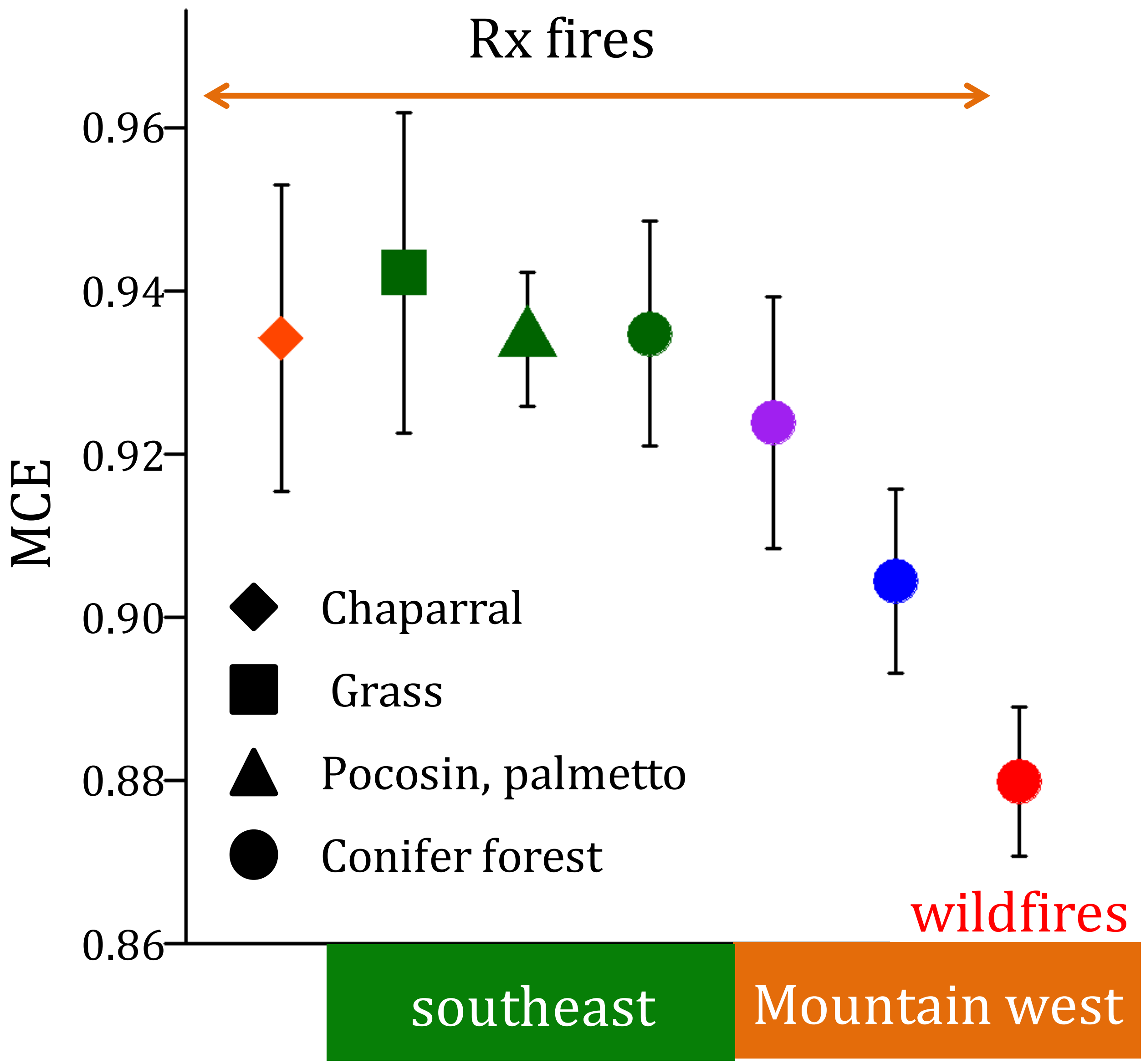
Emission Production Rate

Dispersion/Concentration

Factors potentially influencing $EF_{PM2.5}$

- Combustion phase (flaming, smoldering, glowing)
- Combustion efficiency (CO_2 / total C released)
- Fuel moisture
- Fuel bulk density (packing ratio)
- Fuel composition
- Fire behavior

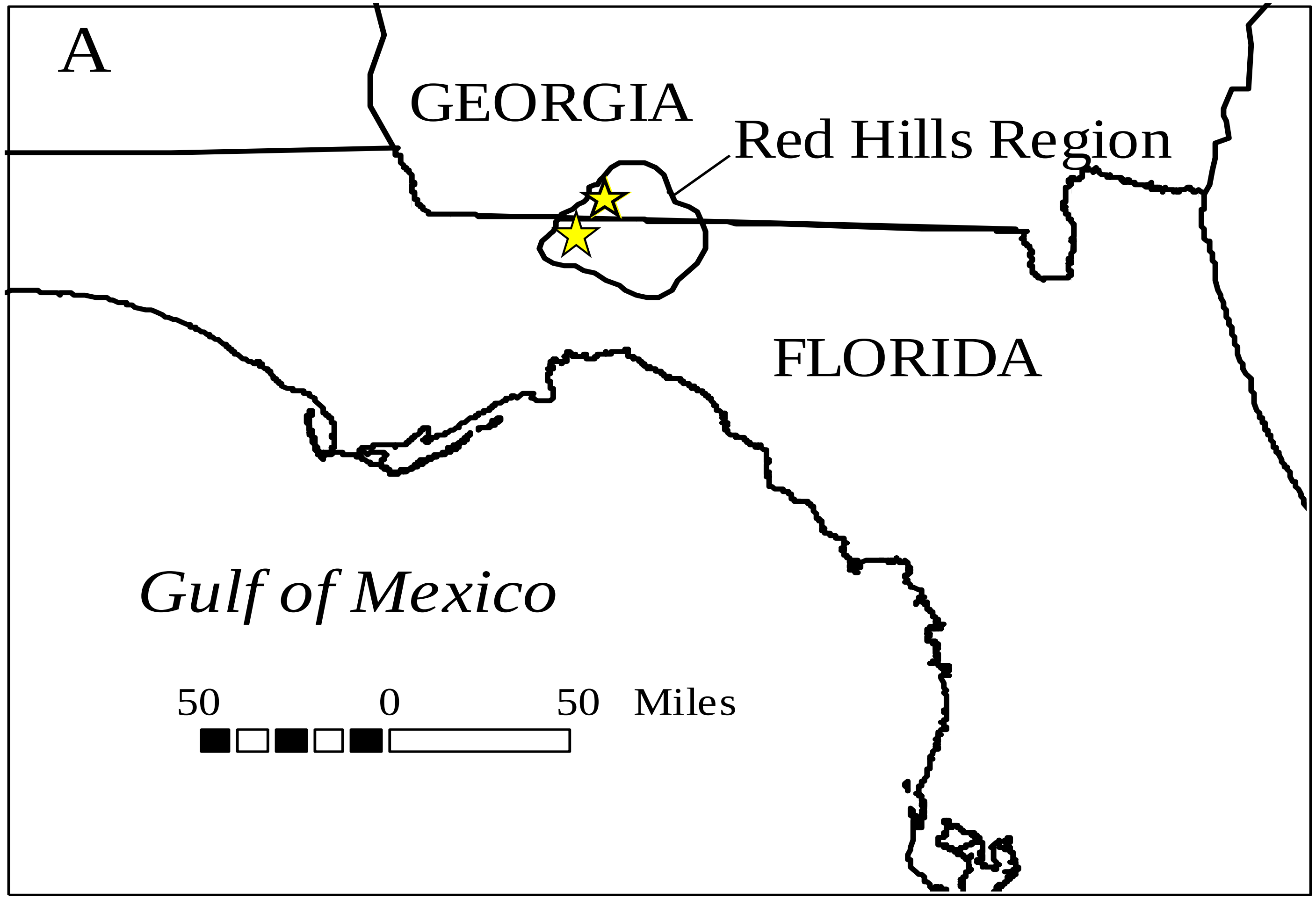
- Community type
- Season
- Weather
- Time since fire



Urbanski et al. 2012

Purpose

- Investigate effects of fire environmental conditions and ecological variables on $PM_{2.5}$ emission factors within southeastern U.S. pine-grassland communities
- Suggest whether or not developing models to predict $PM_{2.5}$ emissions using such conditions as input would improve emissions estimates


A
GEORGIA
Red Hills Region
FLORIDA
Gulf of Mexico
50 0 50 Miles

Methods

- Measure a $EF_{PM2.5}$ in the field from the ground during prescribed burns across a range of common environmental conditions
- Use Structural Equation Modeling to identify variables influencing $EF_{PM2.5}$ and their interactions

Fire Environmental Variables:
Fuel load, moisture, and consumption

- Live herbaceous
- Aerated 1-hr (0-0.6 cm dead grass, pine needles, etc.)
- Fine 1-hr unaerated (smaller particles)
- 10-hr (0.6-2.5 cm)
- Bed depth and density
- Time since fire

Fire Environmental Variables:

Fire behavior

- Heat per unit area (kJ m^{-2})
- Reaction Intensity (kJ m^{-2} s^{-1})
- Fireline Intensity (kJ m^{-1} s^{-1})
- Flaming and smoldering residence time
- Maximum temperature
- Flame length
- Rate of spread
- Ignition type (backing, heading)

Fire Environmental Variables:
Weather

- Relative humidity
- Ambient temperature
- Wind speed
- Keetch-Byrum Drought Index
- Season

Tall Timbers Fire Ecology (Stoddard) Plots

Pebble Hill Fire Plots, Thomasville, Georgia

4 months post-burn

1 year post-burn

3 years post-burn

4 years post-burn

Pebble Hill Fire Plots, Thomasville, Georgia

September 2009

February 2010

Emission factors

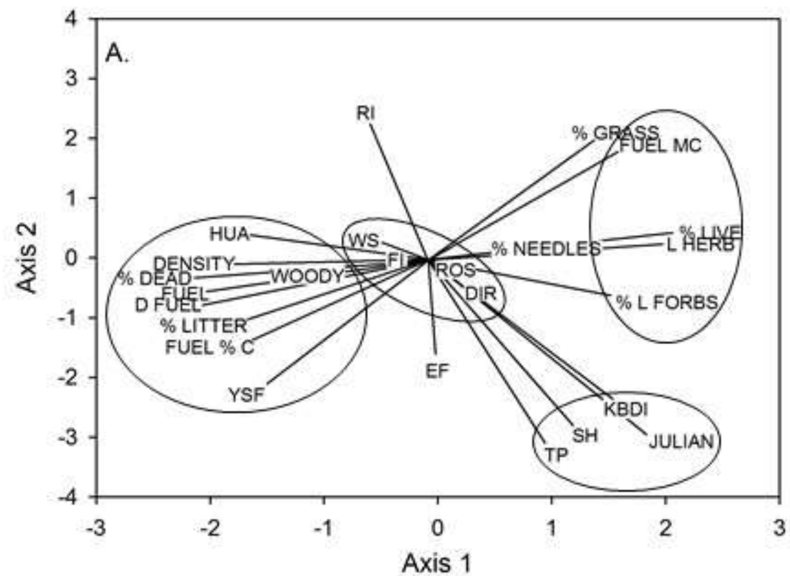
$$EF_{PM} = \frac{\text{PM emitted (g)}}{\text{Fuel consumed (kg)}}$$

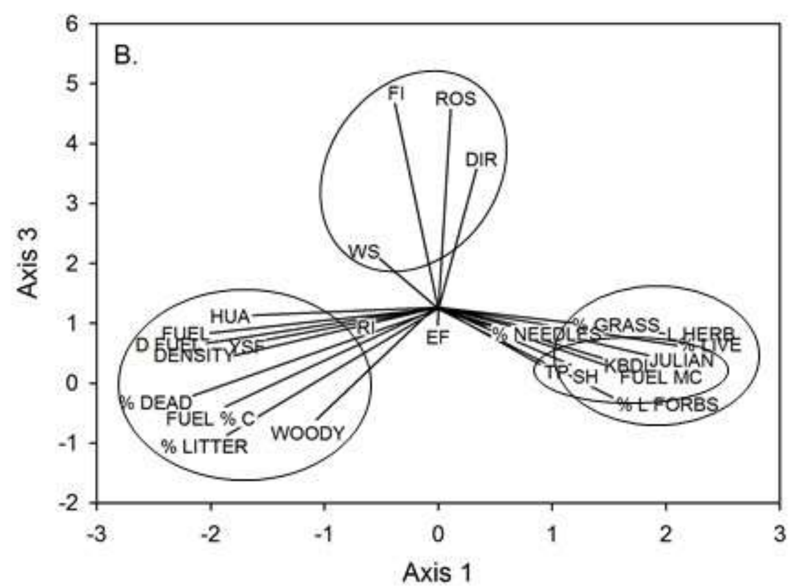
$$EF_{PM} = \frac{PM_{plume} - PM_{ambient}}{C_{plume} - C_{ambient}} * w$$

PM, CO_2, CO
sample

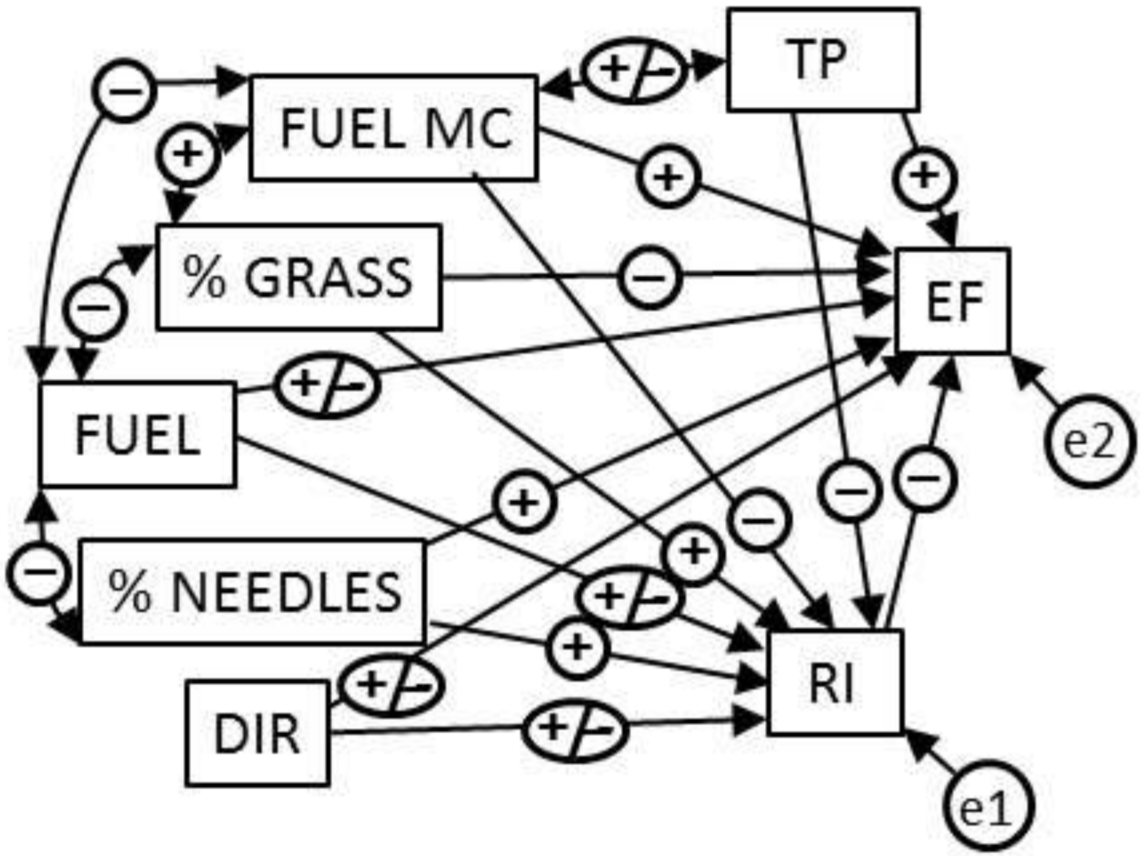
Emission
intake

Principal Component Analysis (PCA) – Reduce variables

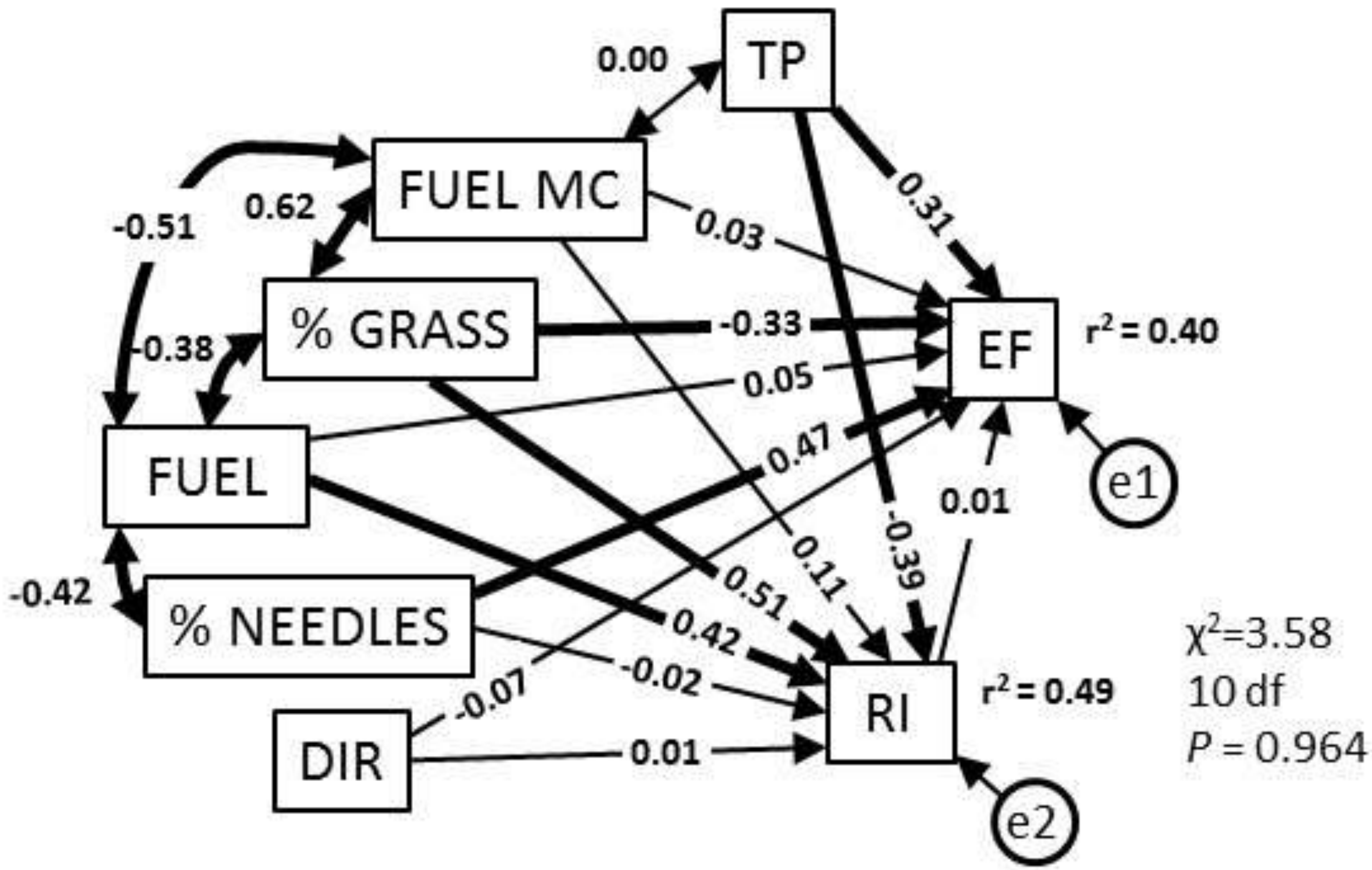




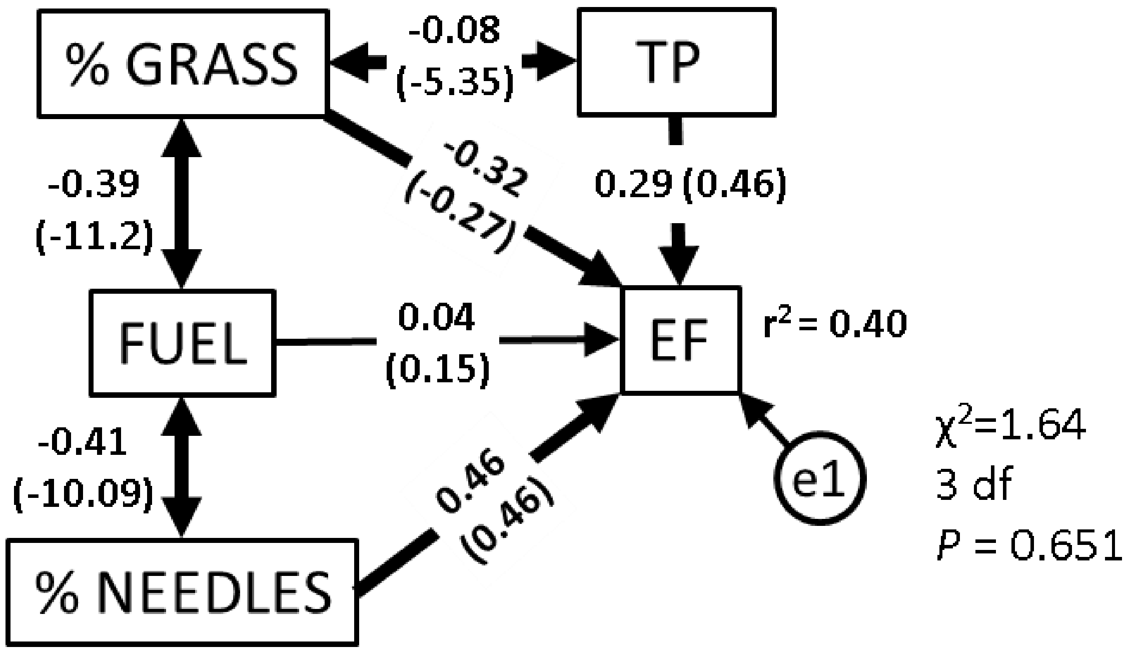
Structural Equation Model (SEM) – Theoretical model



Structural Equation Model (SEM) – Initial model



Structural Equation Model (SEM) – Final model

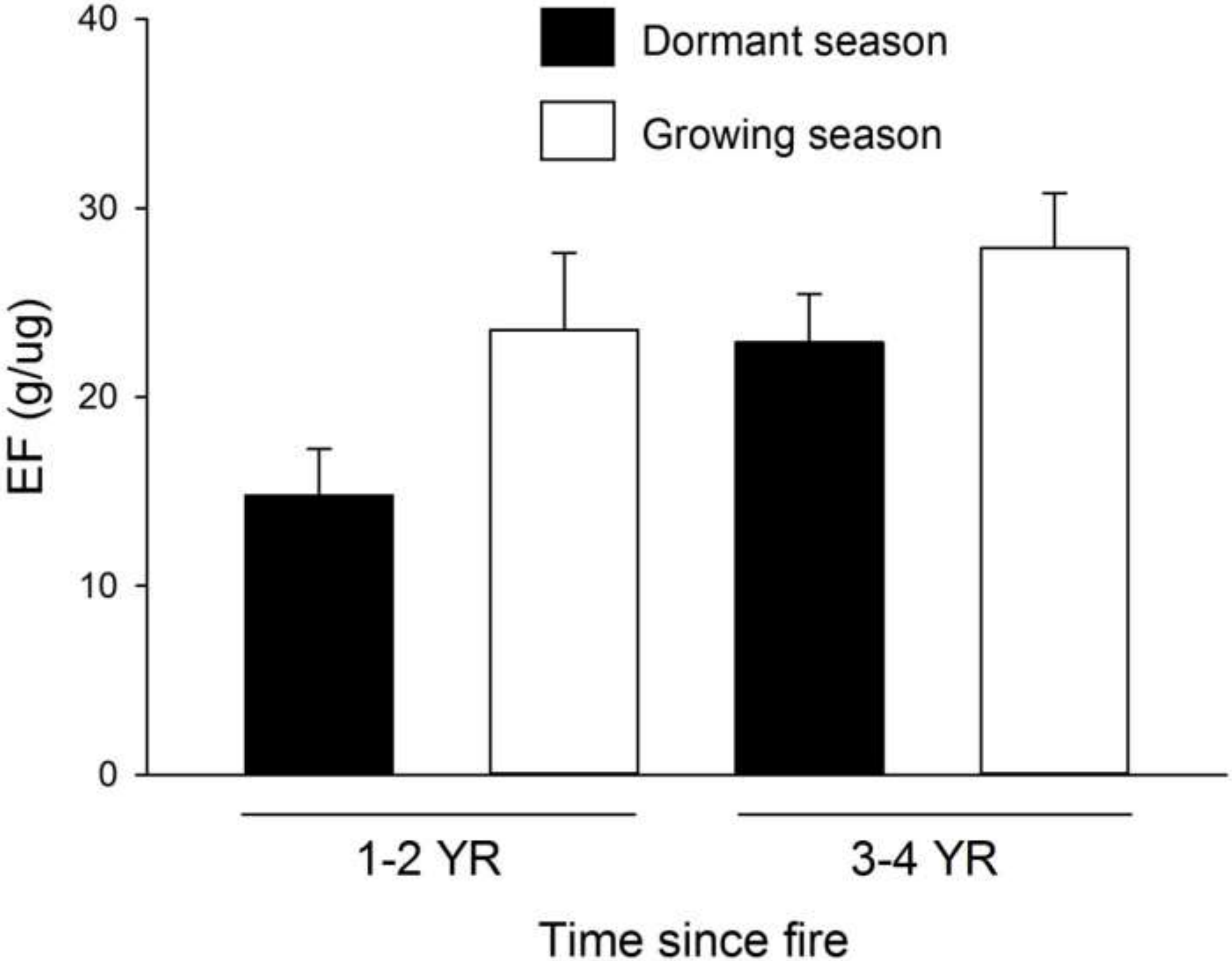


8.4 $m^2\ ha^{-1}$ (36 ft^2/acre)
15% needles
$EF_{PM2.5}$ = 15.4 g kg^{-1}

18 $m^2\ ha^{-1}$ (78 $ft^2\ ac^{-1}$)
29% needles
$EF_{PM2.5}$ = 24.1 g kg^{-1}

TP = 20 C (68 F)
RH = 38
VD = 7.0
$EF_{PM2.5}$ = 18.8 g kg^{-1}

TP = 33 C (91 F)
RH = 47
VD = 15
$EF_{PM2.5}$ = 24.3 g kg^{-1}


Dormant season
Growing season
40
30
20
10
0
EF (g/ug)
1-2 YR
3-4 YR
Time since fire

Conclusions

- Fuel characteristics have significant effects on $EF_{PM2.5}$ in periodically burned southern pine-grasslands
- Lowest $EF_{PM2.5}$ was associated with low pine stocking, high grass loads, frequent burning, and dormant season burns
- Model development for predicting $EF_{PM2.5}$ based on forest structure and fuel composition should improve the accuracy of PM emission estimates
- Low $EF_{PM2.5}$ conditions generally correspond with goals for ecological management of this community type, apart from dormant season burning
- Effect of season on $EF_{PM2.5}$ appears to be because of air moisture rather than fuel moisture
- Growing season burns promote grass cover over time which might offset higher $EF_{PM2.5}$

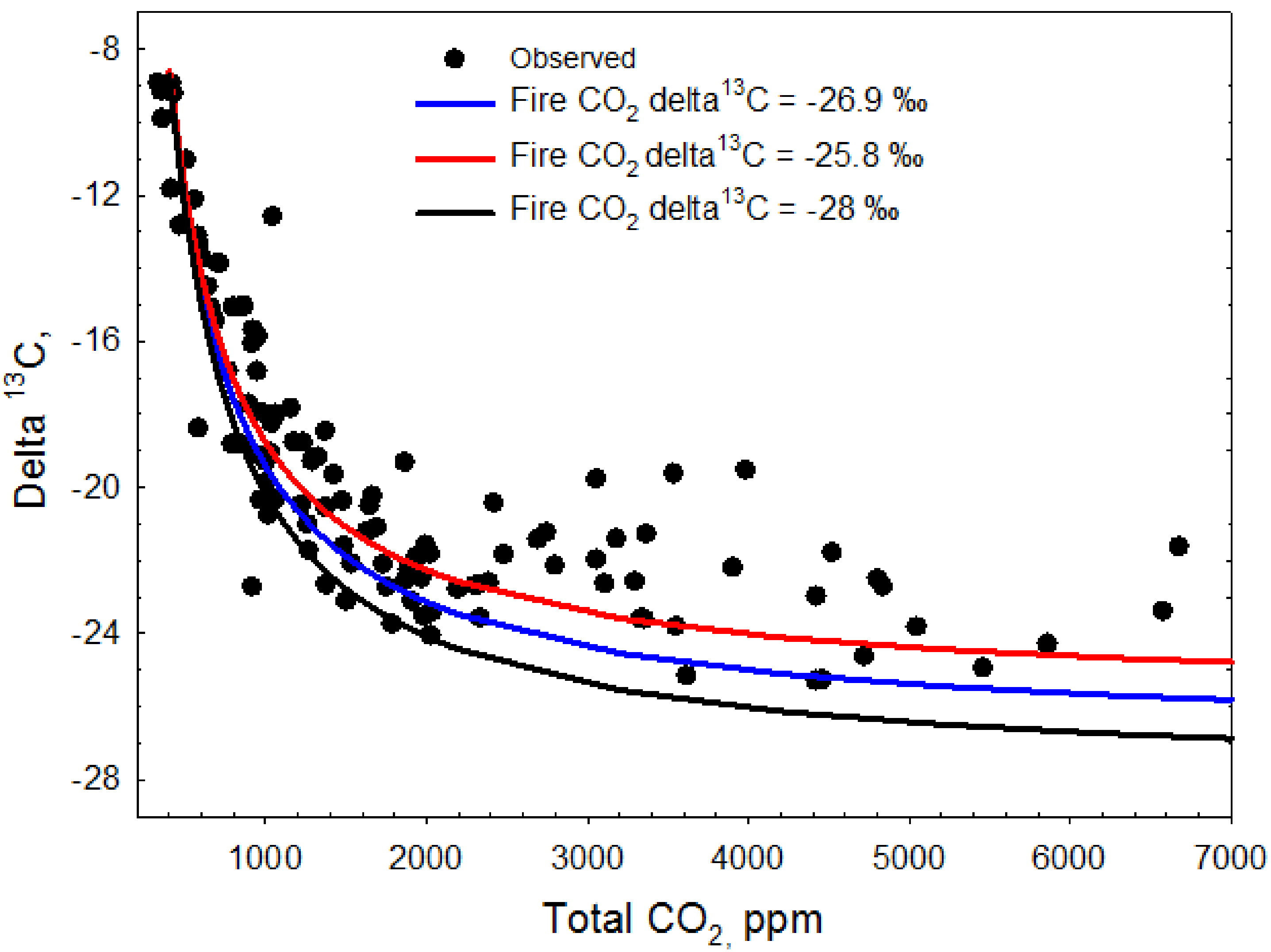
Emission factors

Mass balance method

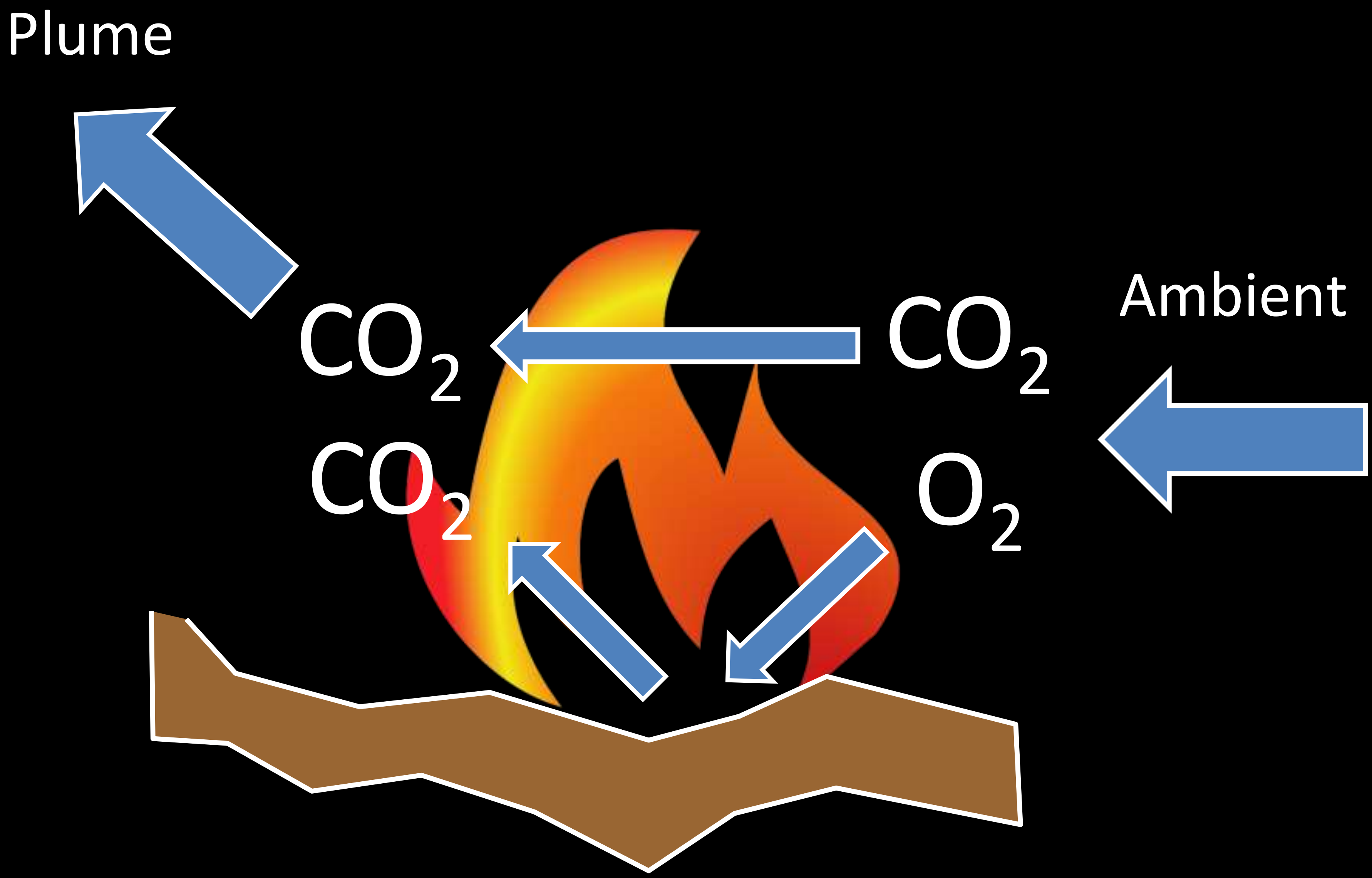
$$EF_{PM} = \frac{PM_{plume} - PM_{ambient}}{C_{PM} + C_{plume} - C_{ambient}} * w$$

Carbon isotope method

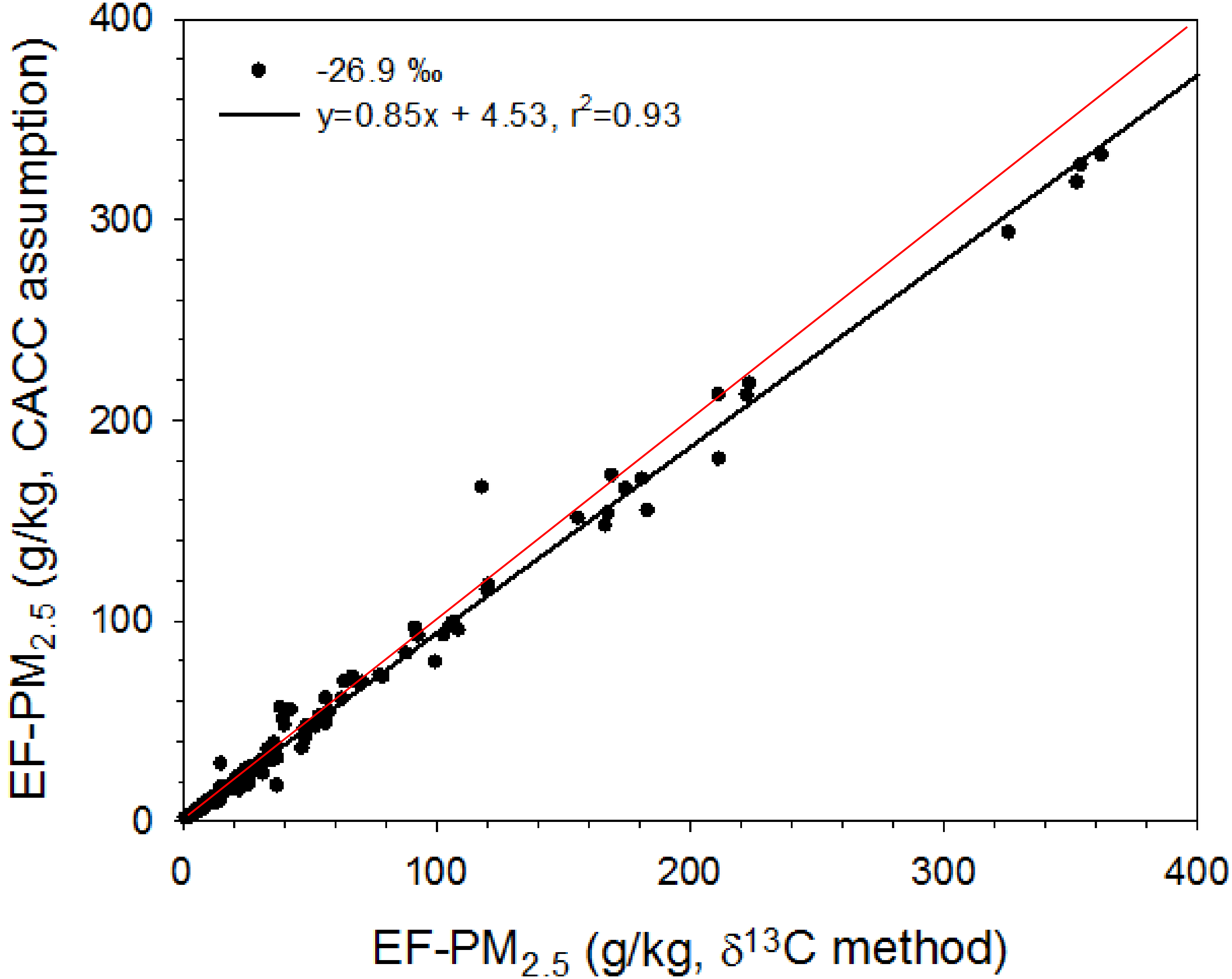
$$EF_{PM} = \frac{PM_{plume} - PM_{ambient}}{C_{PM} + C_{plume}\left(\frac{d13C_{plume} - d13C_{ambient}}{d13C_{fuel} - d13C_{ambient}}\right)} * w$$



Observed
Fire CO2 delta13C = -26.9 ‰
Fire CO2 delta13C = -25.8 ‰
Fire CO2 delta13C = -28 ‰
-8
-12
-16
-20
-24
-28
Delta 13C,
1000
2000
3000
4000
5000
6000
7000
Total CO2, ppm



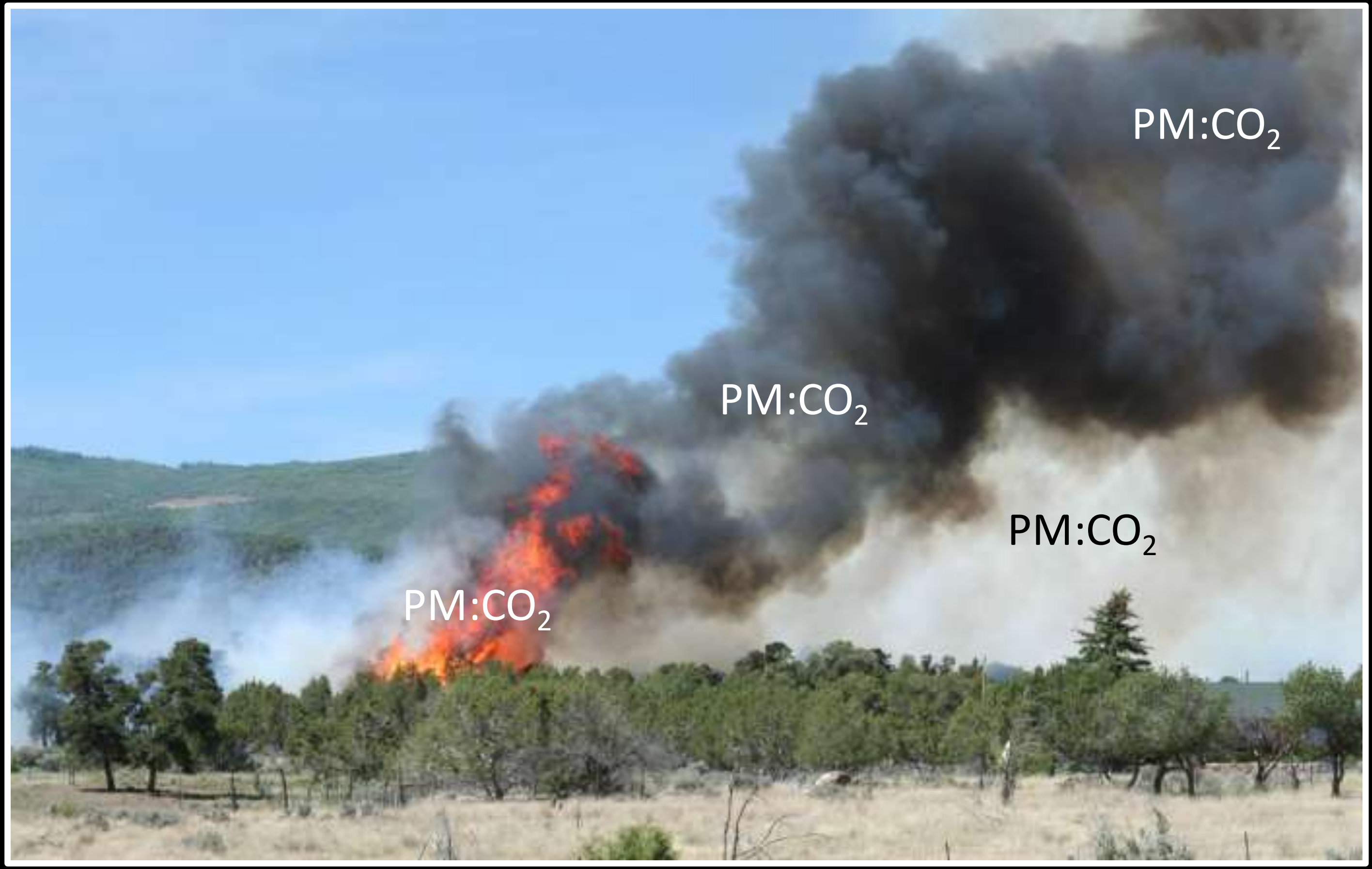
Plume
CO_2
CO_2
Ambient
CO_2
O_2



-26.9 ‰
y=0.85x + 4.53, r²=0.93
EF-PM2.5 (g/kg, CACC assumption)
EF-PM2.5 (g/kg, δ13C method)
0
100
200
300
400
0
100
200
300
400

Emission factor assumption:

PM_{plume} and CO_{2plume} are evenly mixed



Emission factor assumption:
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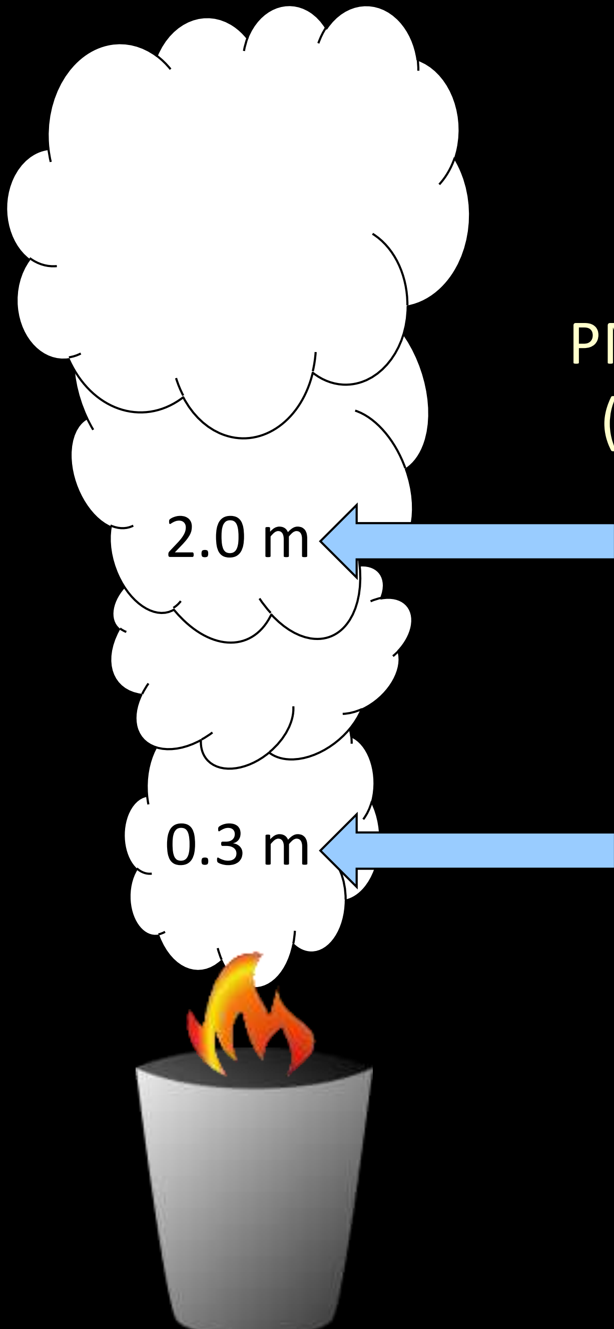
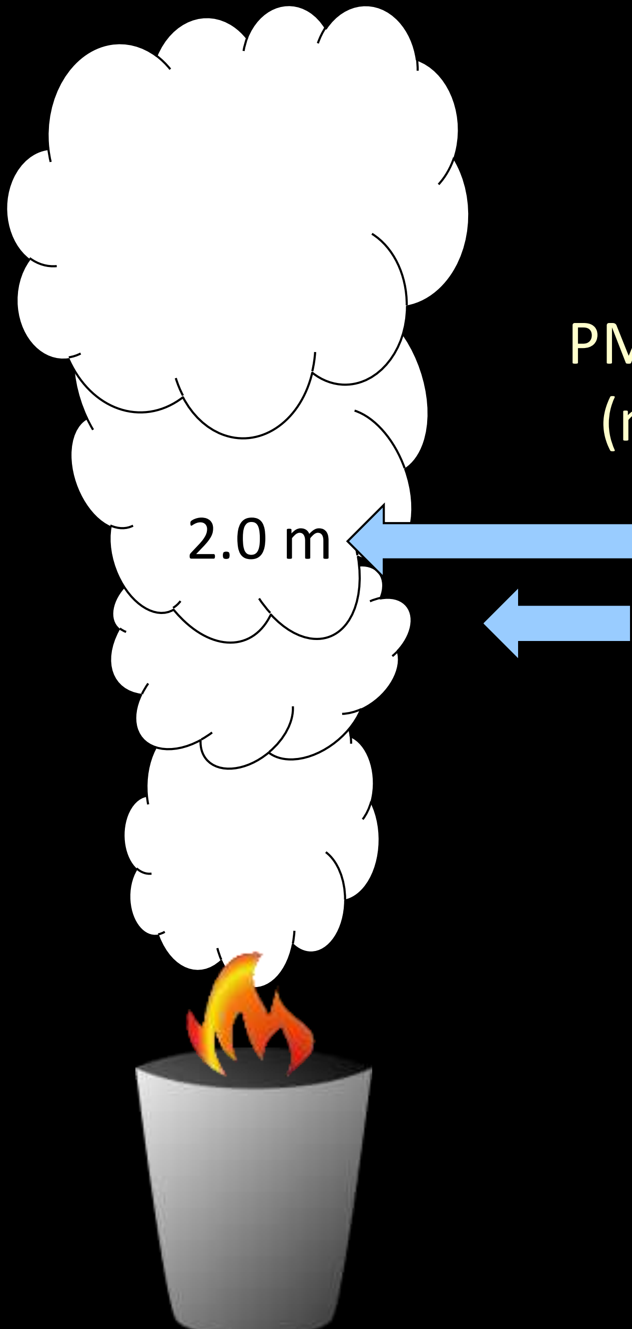
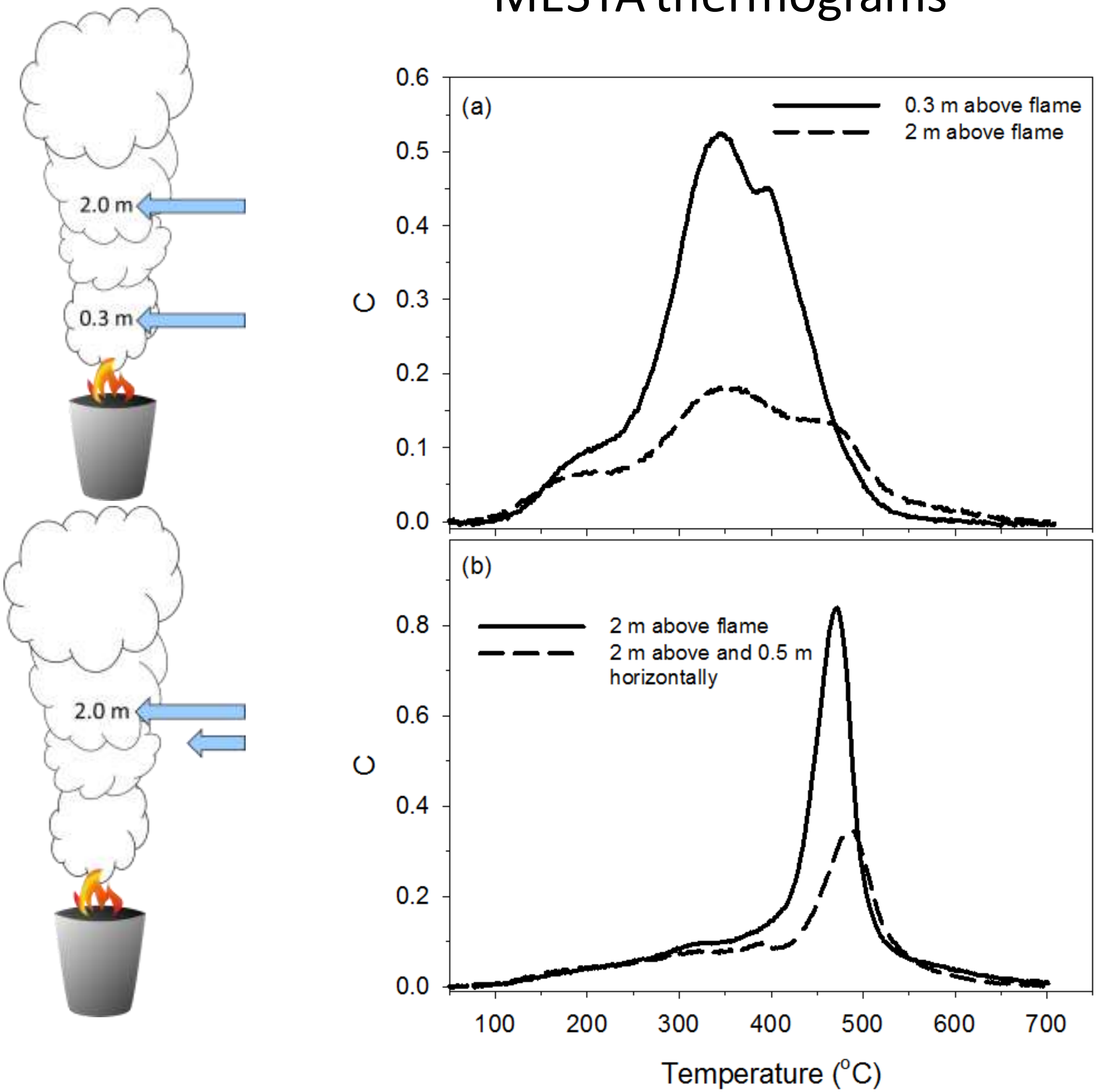


$PM_{2.5}$ conc ($mg\ m^{-3}$)	Fire-CO_2 (ppm)	MCE	$EF_{PM2.5}$ ($g\ kg^{-1}$)
2.3	340	0.97	5.8
20.4	3020	0.91	5.3



$PM_{2.5}$ conc ($mg\ m^{-3}$)	Fire-CO_2 (ppm)	MCE	$EF_{PM2.5}$ ($g\ kg^{-1}$)
1.4	255	0.94	5.3
3.1	56	0.94	46.4

MESTA thermograms



Conclusions

- Ambient CO_2 concentrations are increased in the fire plume relative to ambient air conditions
- There is a non-stoichiometric relationship between ambient CO_2 + O_2 and gaseous products of combustion that results in a systematic 15% (±2%) under-estimation of $EF_{PM2.5}$ using the traditional mass balance method
- The assumption that emitted $PM_{2.5}$ and CO_2 are well mixed holds true only within flaming combustion convection column
- Conversely, emitted $PM_{2.5}$ and CO_2 are rapidly decoupled (<1 hr) where convective mixing is weak
- Such conditions might include the turbulent edges and exterior of convection columns and convection from low-energy combustion (low intensity flaming or smoldering combustion)

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