Analysis of Vertical Fire Emissions Distribution in CMAQ

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Objective:

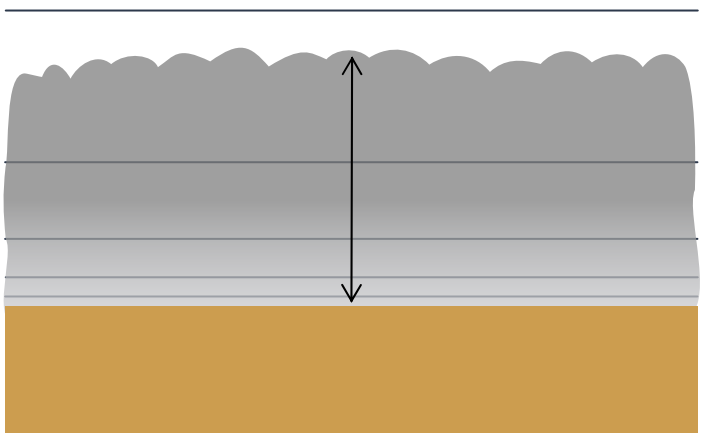
- Evaluate the uncertainties related to fire air quality modeling with 3D photochemical models
- Sensitivity analyses:
  - Emissions
  - Resolution
  - Meteorology
  - <u>Plume rise</u>

Typical Approaches for Estimating Plume Rise

- **Theoretical Maximum:**

$$\Delta H_{\max,i} = \min \begin{cases} F_i^{0.6} * 38.7/W_i' \\ 2.4 * \left[F_i/\left(W_i' * s_i\right)\right]^{0.333} * 38.7/W_i' \end{cases}$$

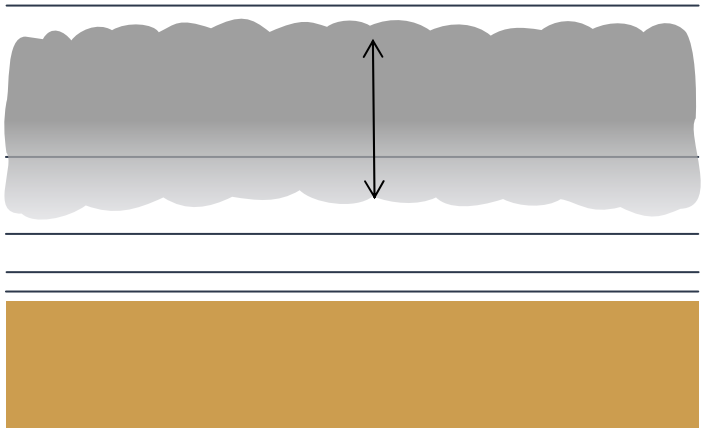
$$\Delta H_{\max,i} = F_i^{0.6} * 38.7/W_i'$$



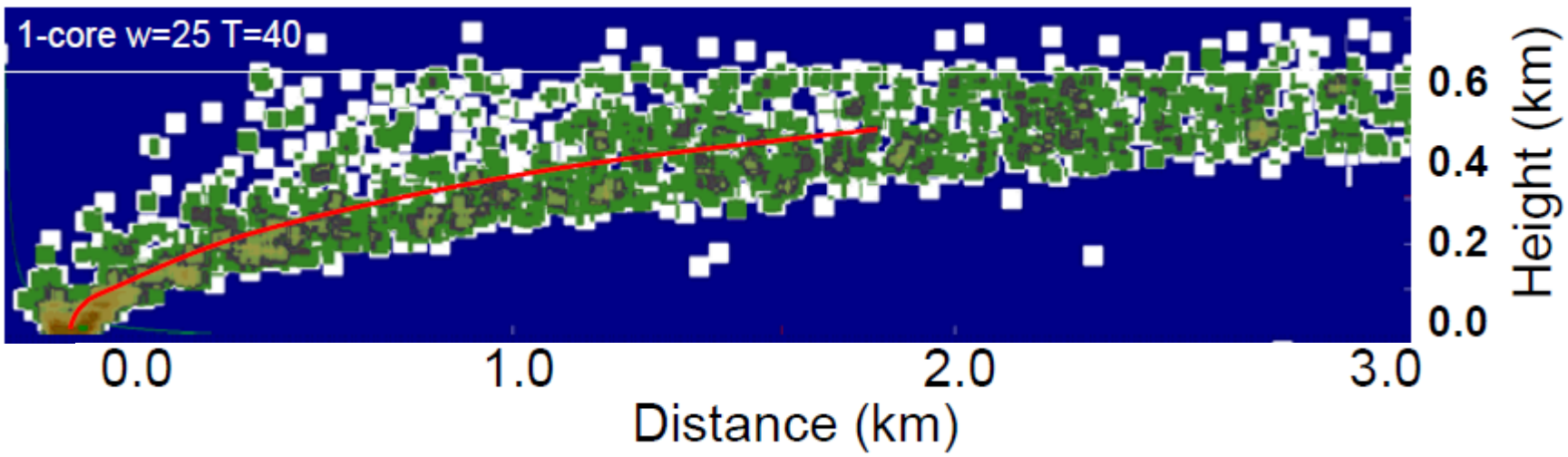
- **Empirical Maximum and Minimum:**

$$\Delta H_{F-\min,i} = P_{Bot} - \left(\frac{P_{Bot}}{e^1}\right) * e^{\left(1-AR_1/AR_{Bot}\right)}$$

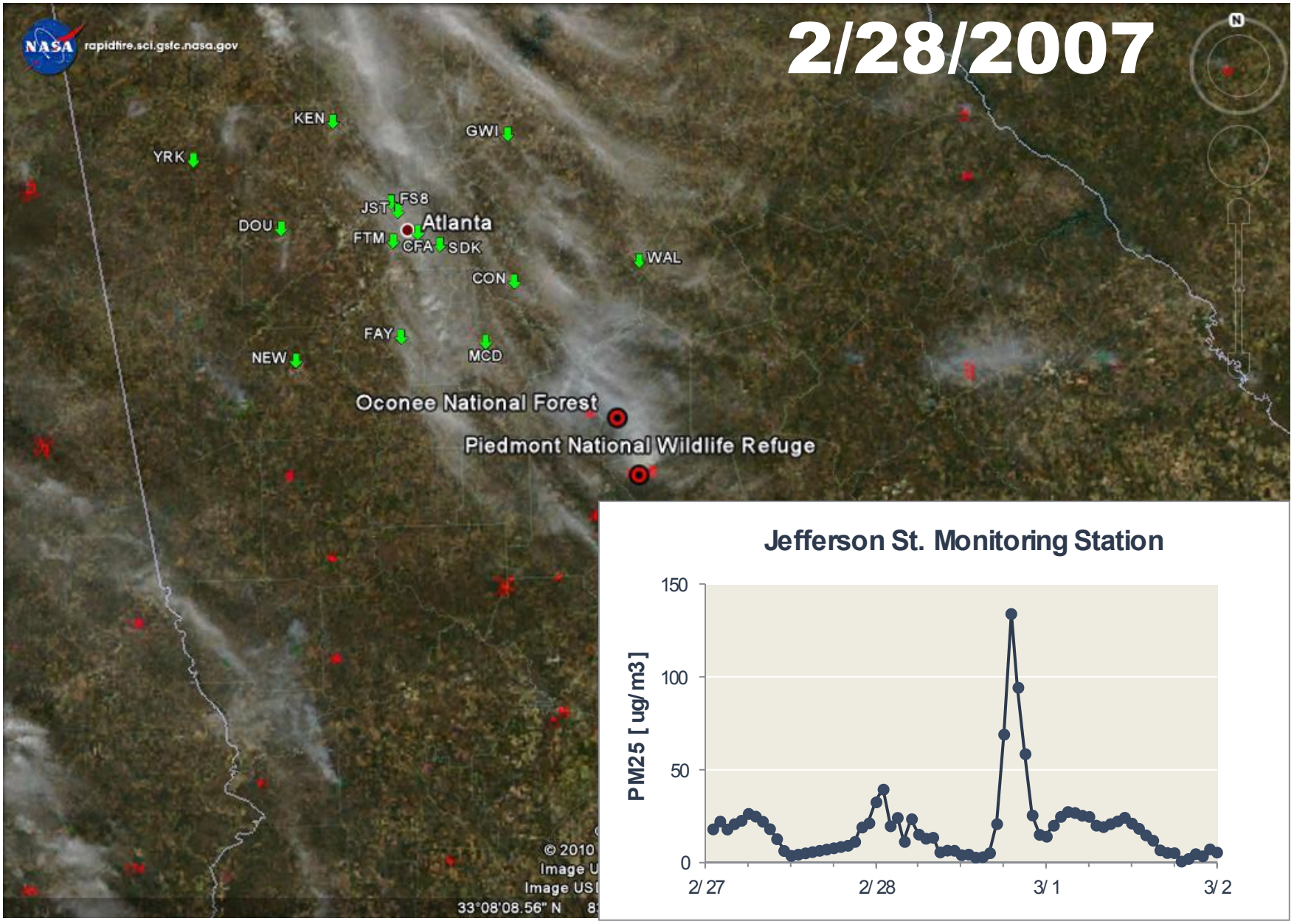
$$\Delta H_{F-\max,i} = P_{Top} - \left(\frac{P_{Top}}{e^1}\right) * e^{\left(1-AR_1/AR_{Top}\right)}$$



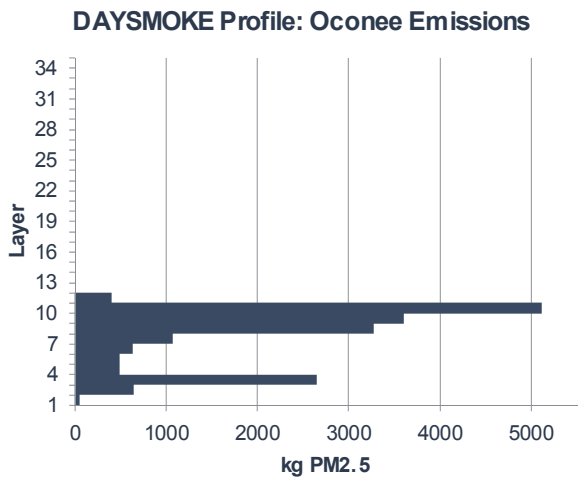
DAYSMOKE

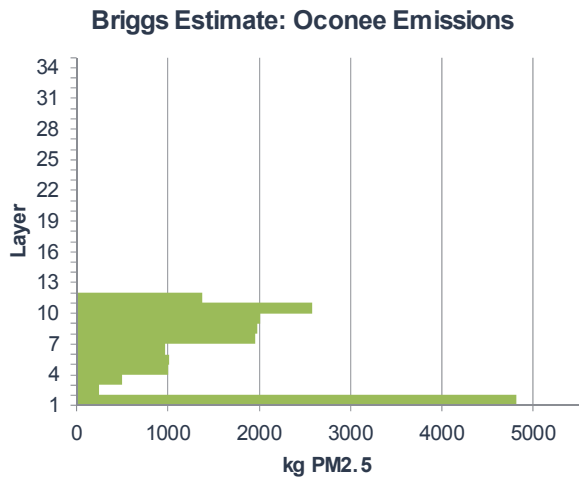


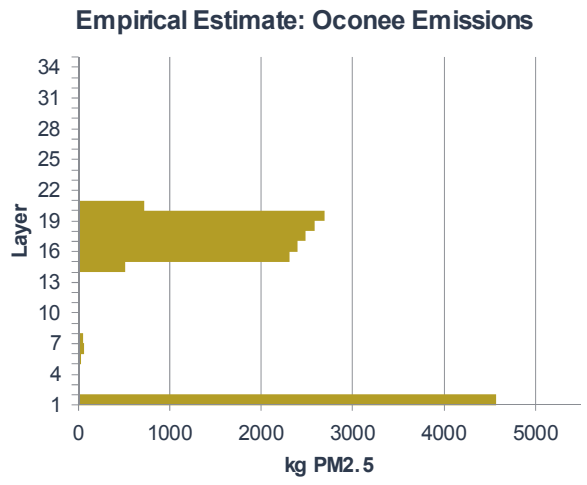
- Empirical-statistical plume rise and dispersion model
- Provides a vertical emissions profile for smoke injection into regional scale air quality models

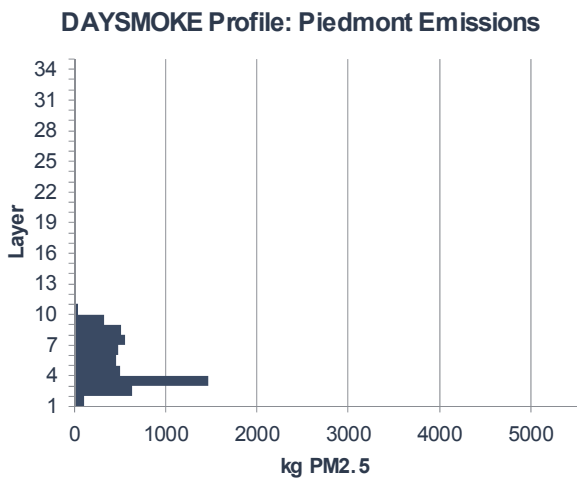

2/28/2007
rapidfire.sci.gsfc.nasa.gov
KEN
GWI
YRK
JST
FS8
Atlanta
DOU
FTM
CFA
SDK
WAL
CON
FAY
NEW
MCD
Oconee National Forest
Piedmont National Wildlife Refuge
Jefferson St. Monitoring Station
PM25 [ug/ m3]
150
100
50
0
2/ 27
2/ 28
3/ 1
3/ 2

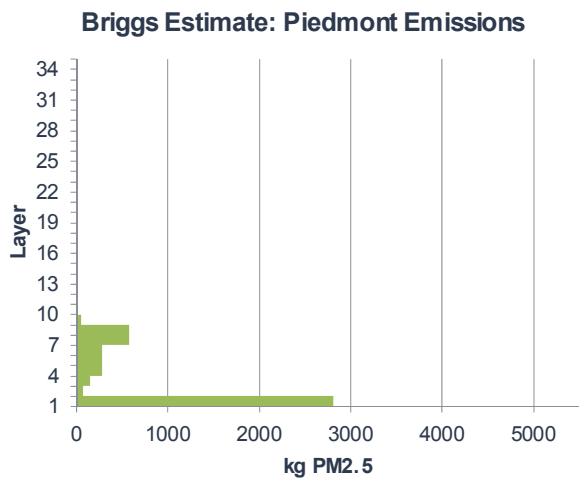
Vertical Plume Profiles

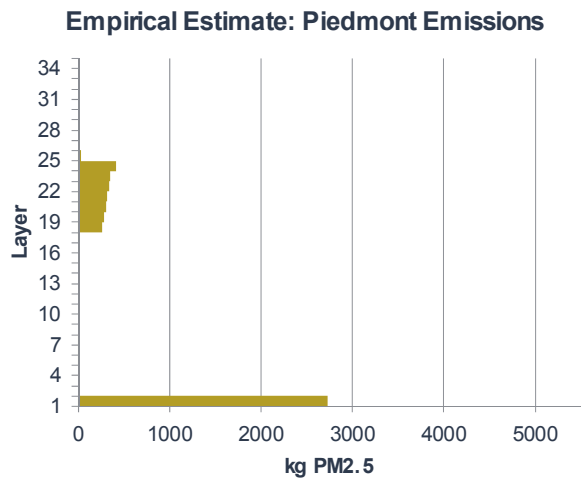






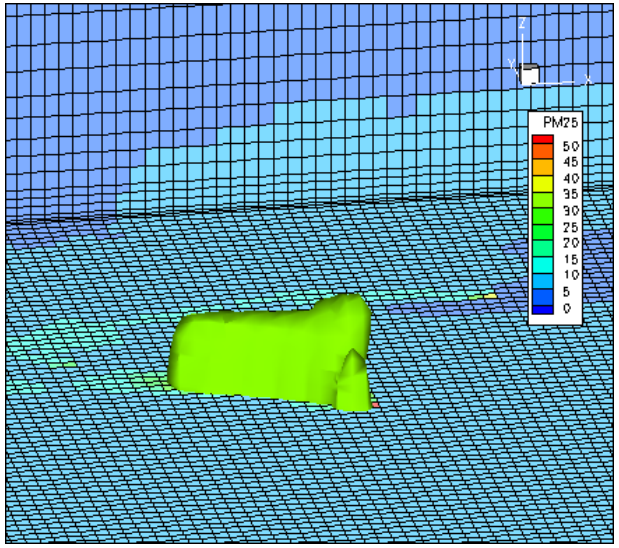




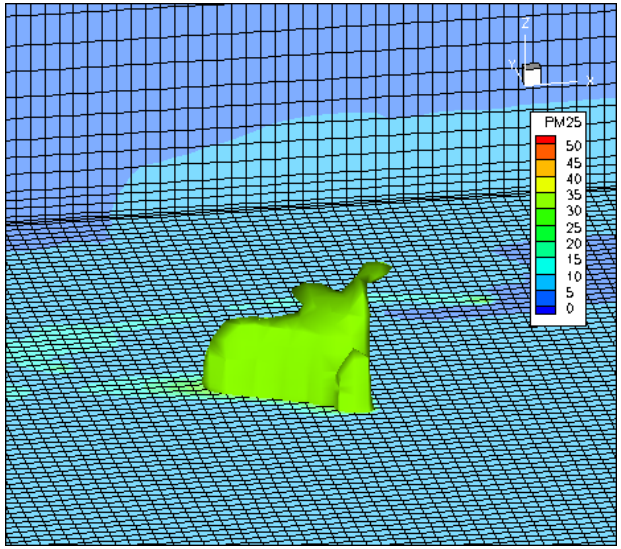


Vertical Plume Profiles

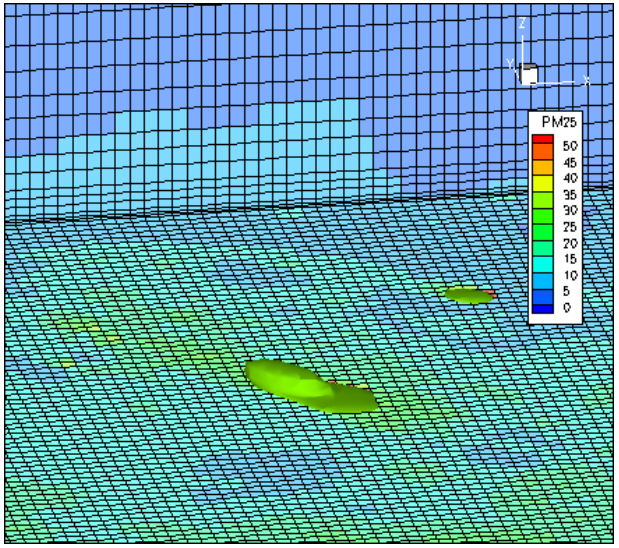
DAYSMOKE



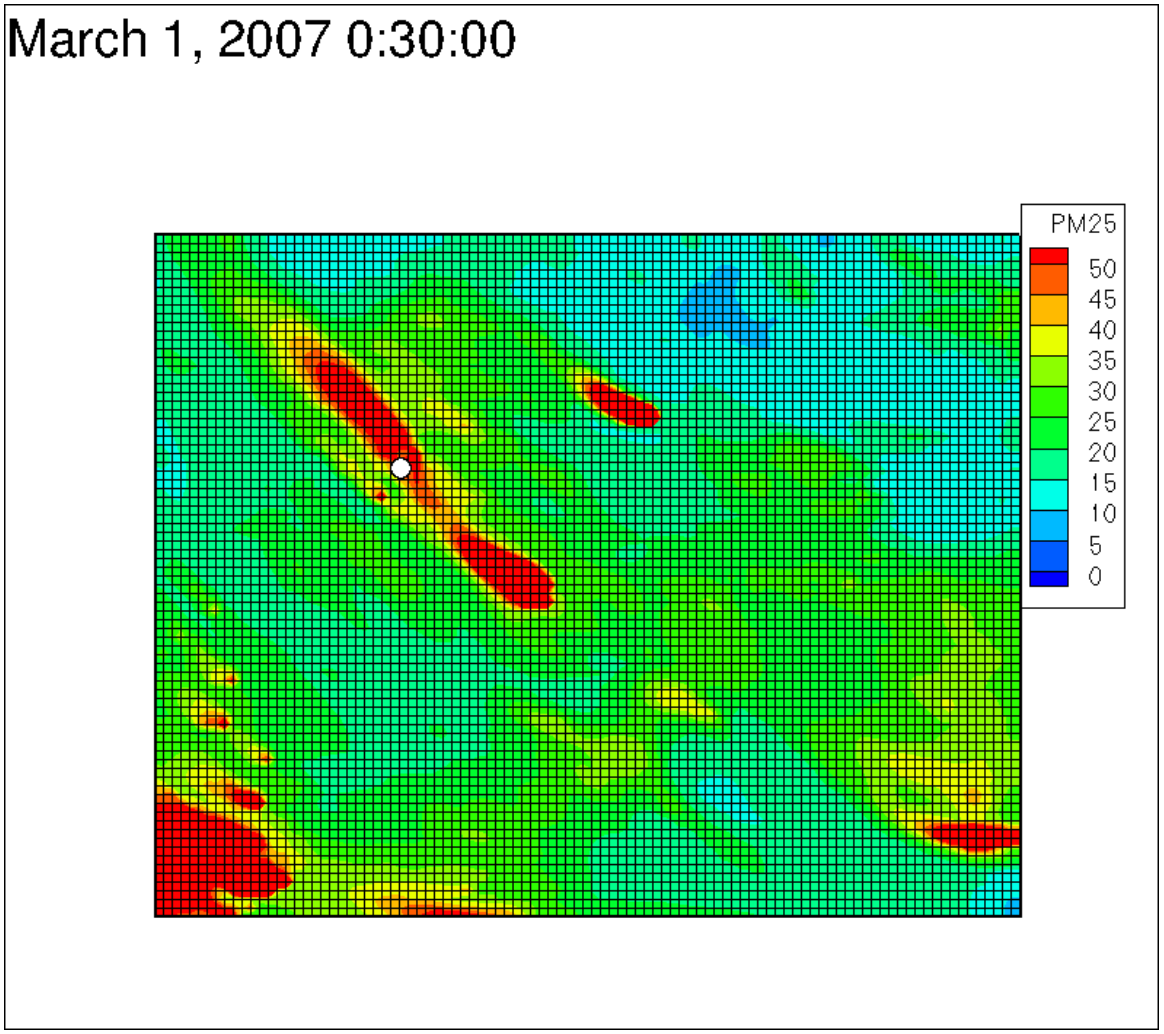
Briggs Estimate



Empirical Estimate



Benchmark CMAQ Simulation with DAYSMOKE Vertical Profile



Fire Emissions:

Fire emissions Production Simulator (FEPS)

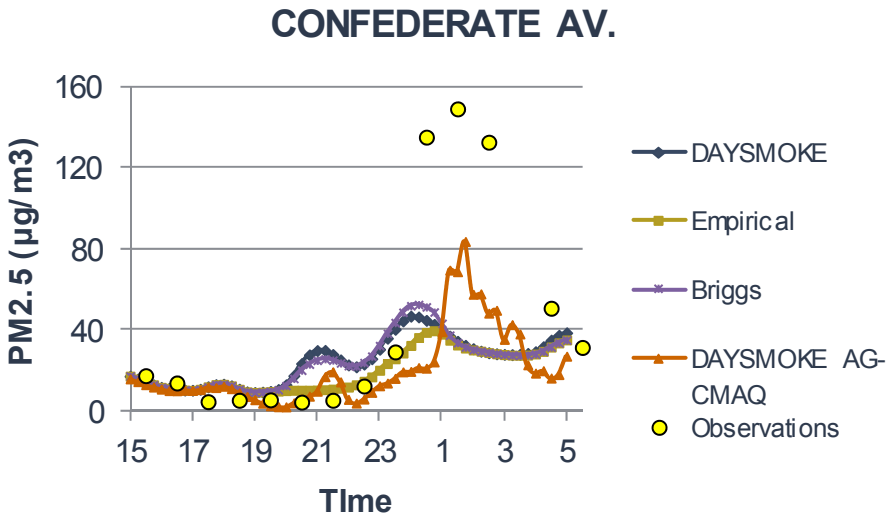
Background Emissions:

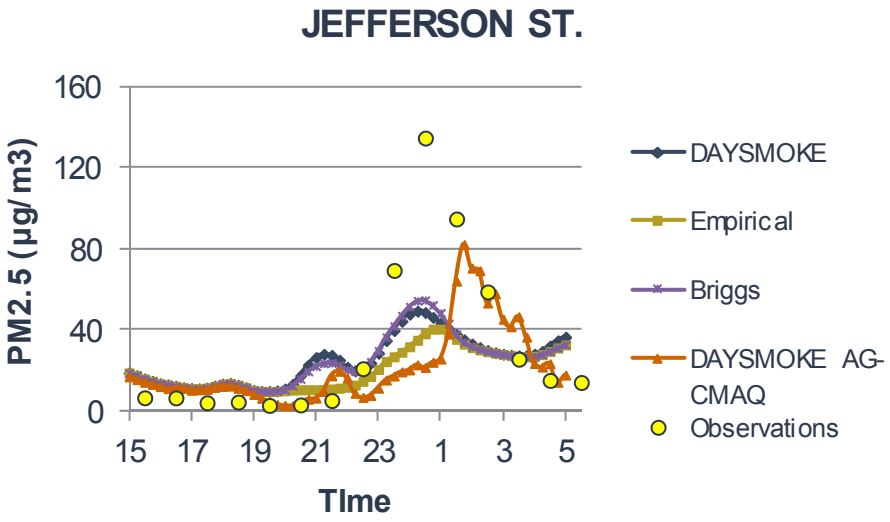
SMOKE with projected 2002 “typical year” inventory

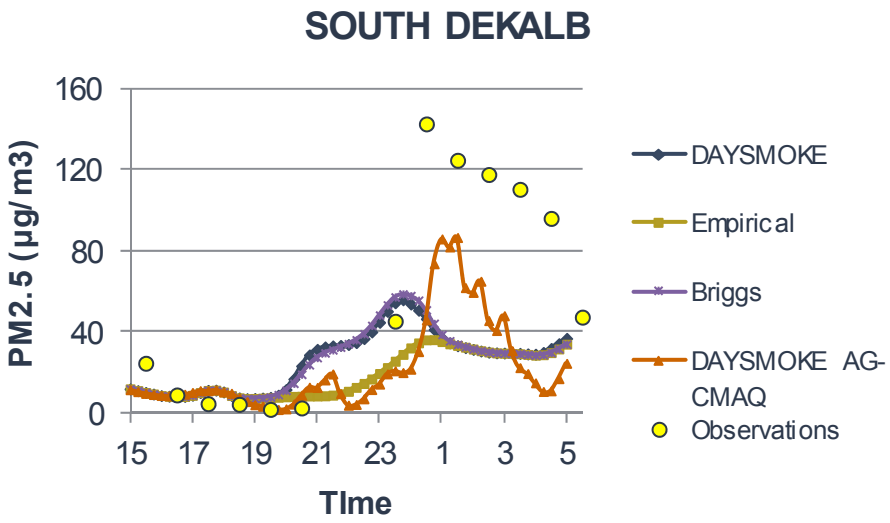
Meteorology:

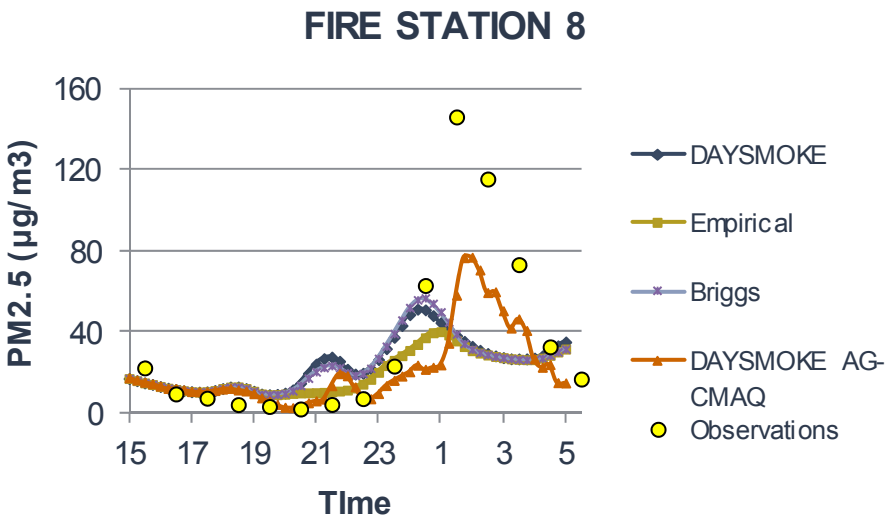
Weather Research & Forecasting model (WRF)

Receptor Impacts









1st Order Sensitivity Analysis

$$C_{x+\Delta x} = C_x + \frac{dC}{dx}(\Delta x) + \frac{1}{2}\frac{d^2C}{dx^2}(\Delta x)^2 + \frac{1}{6}\frac{d^3C}{dC^3}(\Delta x)^3 + H.O.T.$$

$$C_{x-\Delta x} = C_x + \frac{dC}{dx}(-\Delta x) + \frac{1}{2}\frac{d^2C}{dx^2}(-\Delta x)^2 + \frac{1}{6}\frac{d^3C}{dC^3}(-\Delta x)^3 + H.O.T.$$

$$C_{x+\Delta x} - C_{x-\Delta x} = 2\frac{dC}{dx}(\Delta x) + \frac{1}{3}\frac{d^3C}{dC^3}(\Delta x)^3 + H.O.T.$$

$$\frac{C_{x+\Delta x} - C_{x-\Delta x}}{\frac{2(\Delta x)}{x}} = \frac{dC}{dx}x = S$$

Brute Force Analysis of Concentration Sensitivity to Fire Emissions

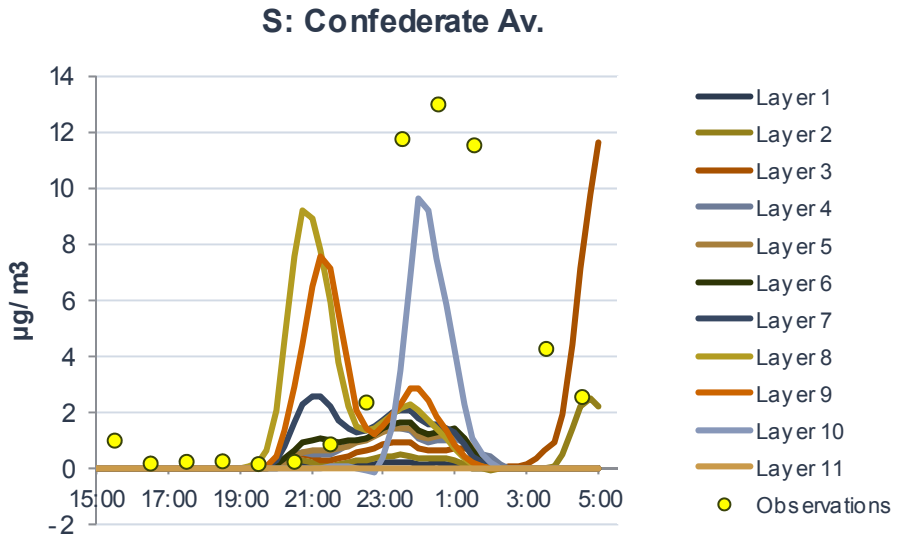
$$S = \frac{C_{(E+\Delta E)} - C_{(E-\Delta E)}}{\frac{2(\Delta E)}{E}}$$

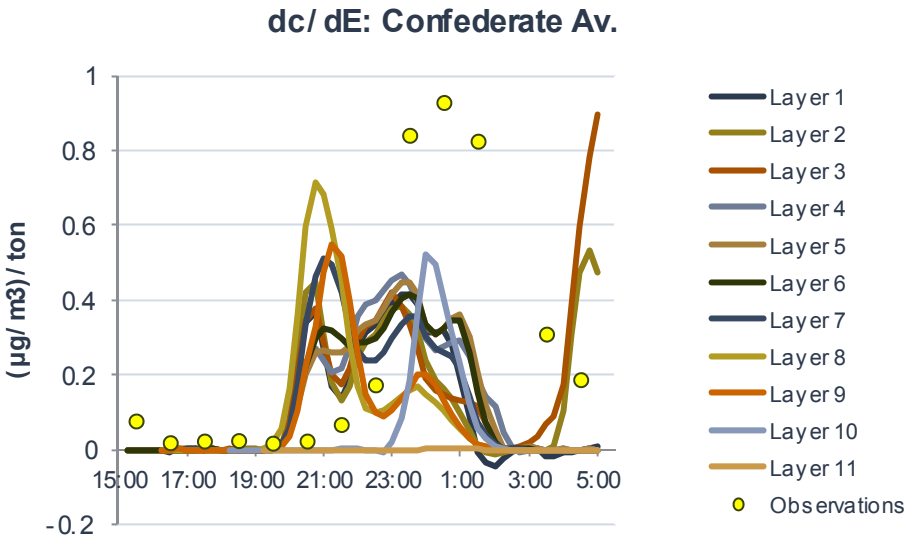
$$\frac{dC}{dE} = \frac{S}{E}$$

$$S_{(10\%)} = \frac{C_{+10\%} - C_{-10\%}}{2(0.1)}$$

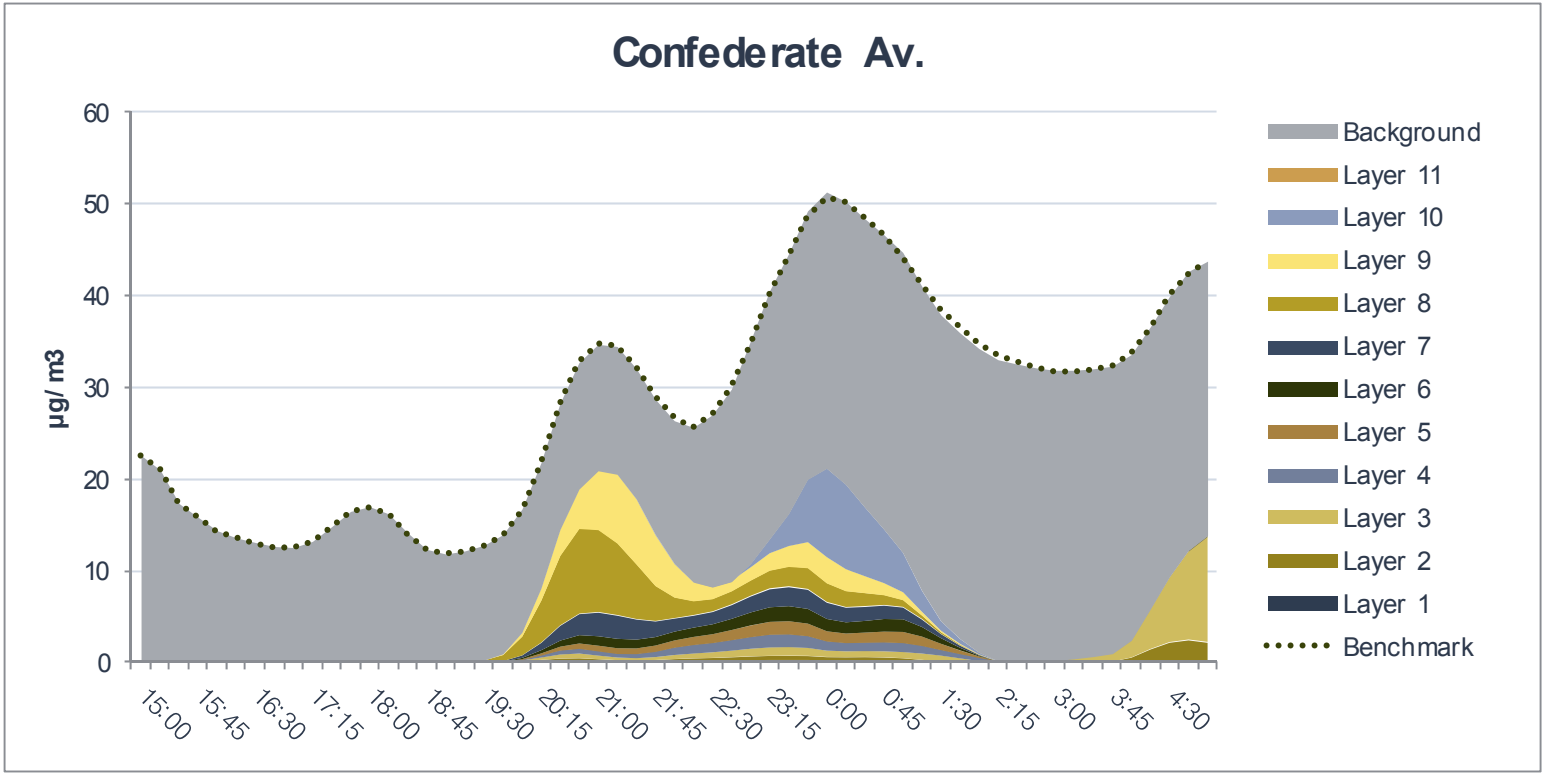
$$S_{LAY\ i} = \frac{C_{(E+\Delta E)_{LAY\ i}} - C_{(E-\Delta E)_{LAY\ i}}}{\frac{2(\Delta E)}{E}_{LAY\ i}}$$

Brute Force Sensitivity to Fire Emissions by Vertical Layer ($S_{10\%}$)

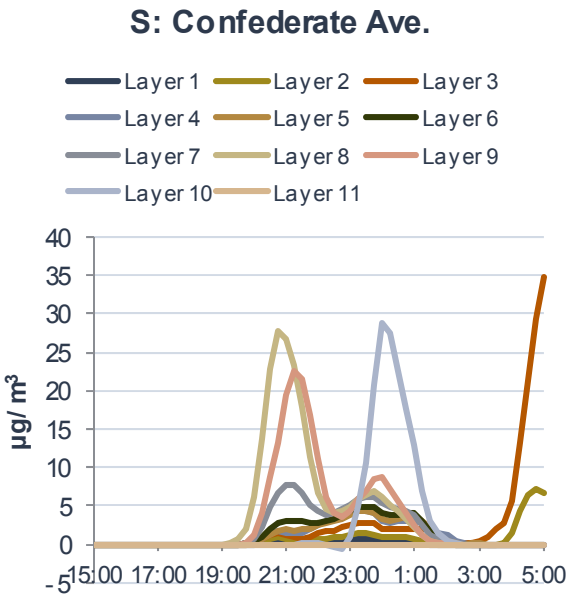


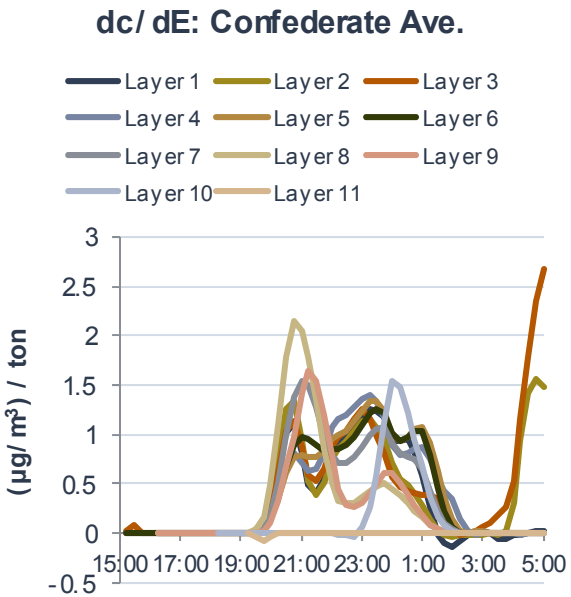


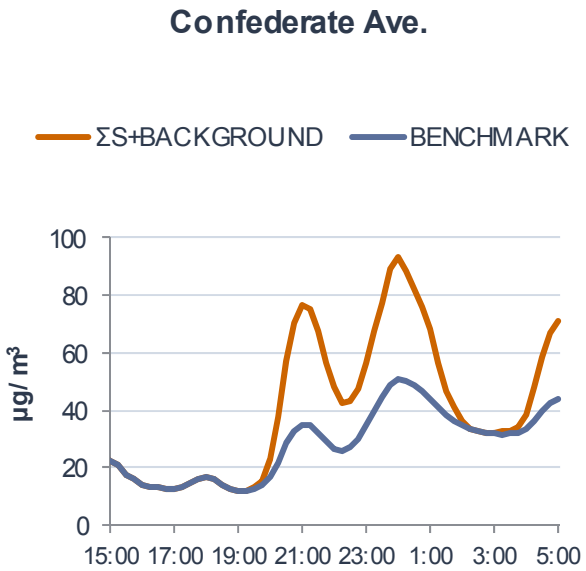
Impact Estimated from $\Sigma S_{10\%}$



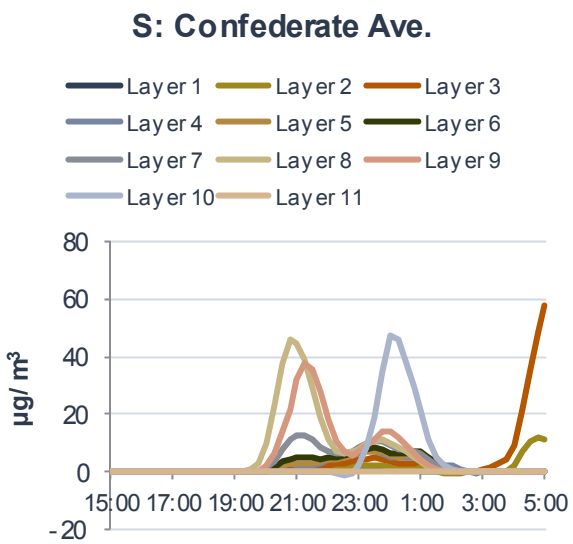
$S_{30\%}$:

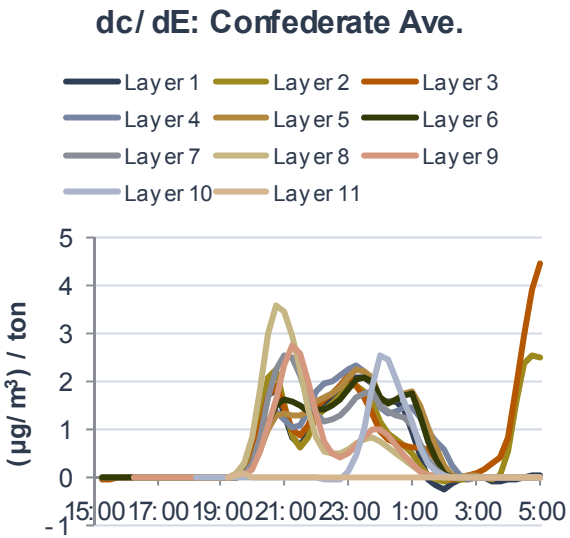

S: Confederate Ave.
Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Layer 7
Layer 8
Layer 9
Layer 10
Layer 11
µg/ m³
40
35
30
25
20
15
10
5
0
-5
15:00 17:00 19:00 21:00 23:00 1:00 3:00 5:00

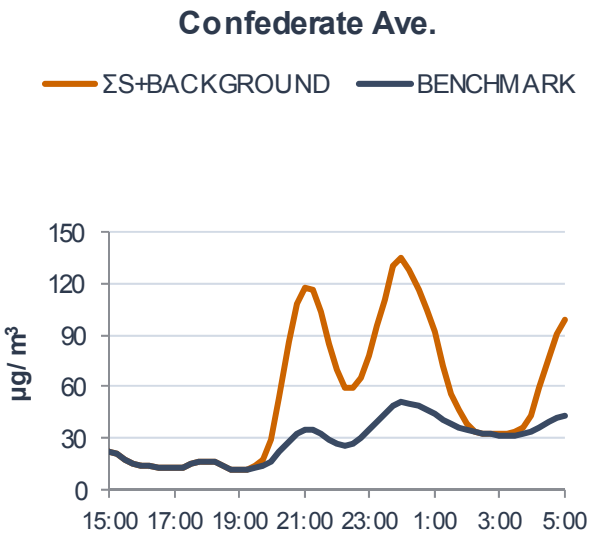

dc/ dE: Confederate Ave.
Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Layer 7
Layer 8
Layer 9
Layer 10
Layer 11
(µg/ m³) / ton
3
2.5
2
1.5
1
0.5
0
-0.5
15:00 17:00 19:00 21:00 23:00 1:00 3:00 5:00


Confederate Ave.
ΣS+BACKGROUND
BENCHMARK
µg/ m³
100
80
60
40
20
0
15:00 17:00 19:00 21:00 23:00 1:00 3:00 5:00

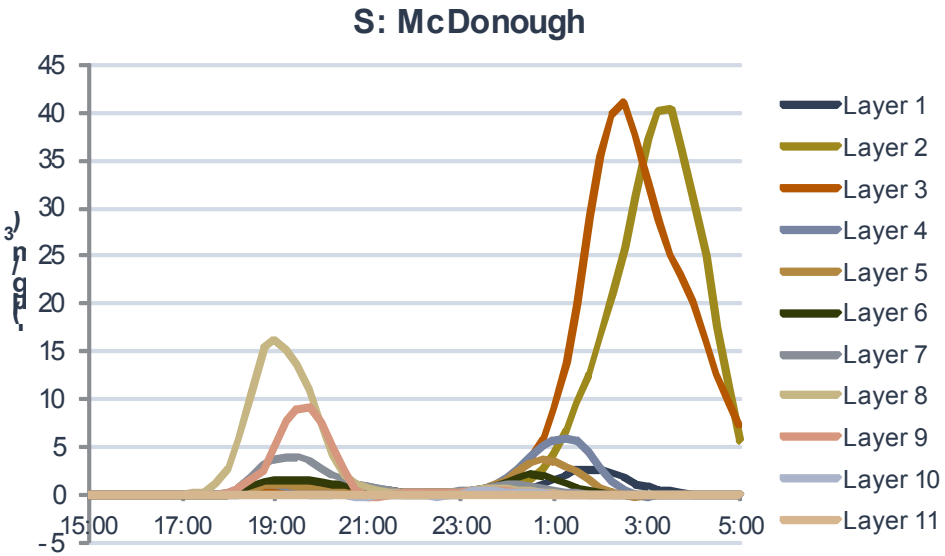
$S_{50\%}$:

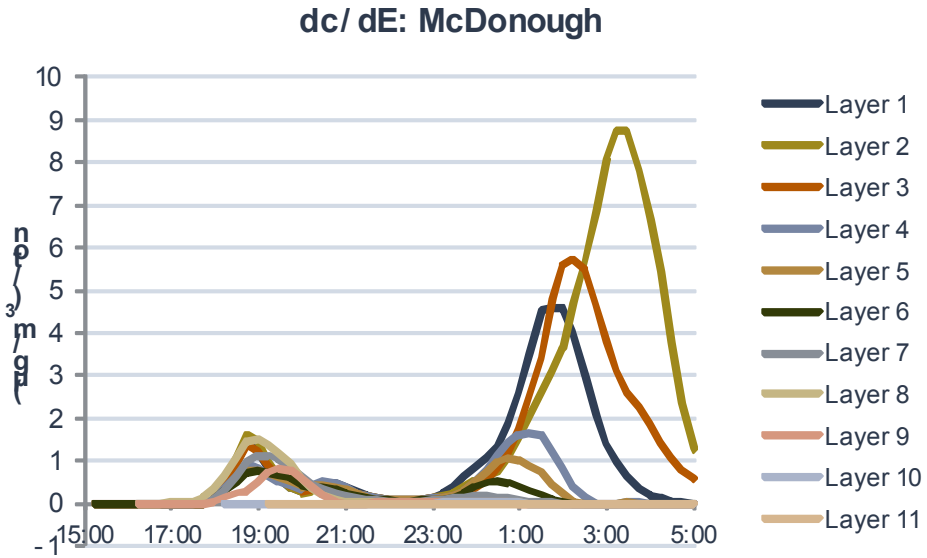

S: Confederate Ave.
Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Layer 7
Layer 8
Layer 9
Layer 10
Layer 11
µg/ m³
80
60
40
20
0
-20
15:00 17:00 19:00 21:00 23:00 1:00 3:00 5:00

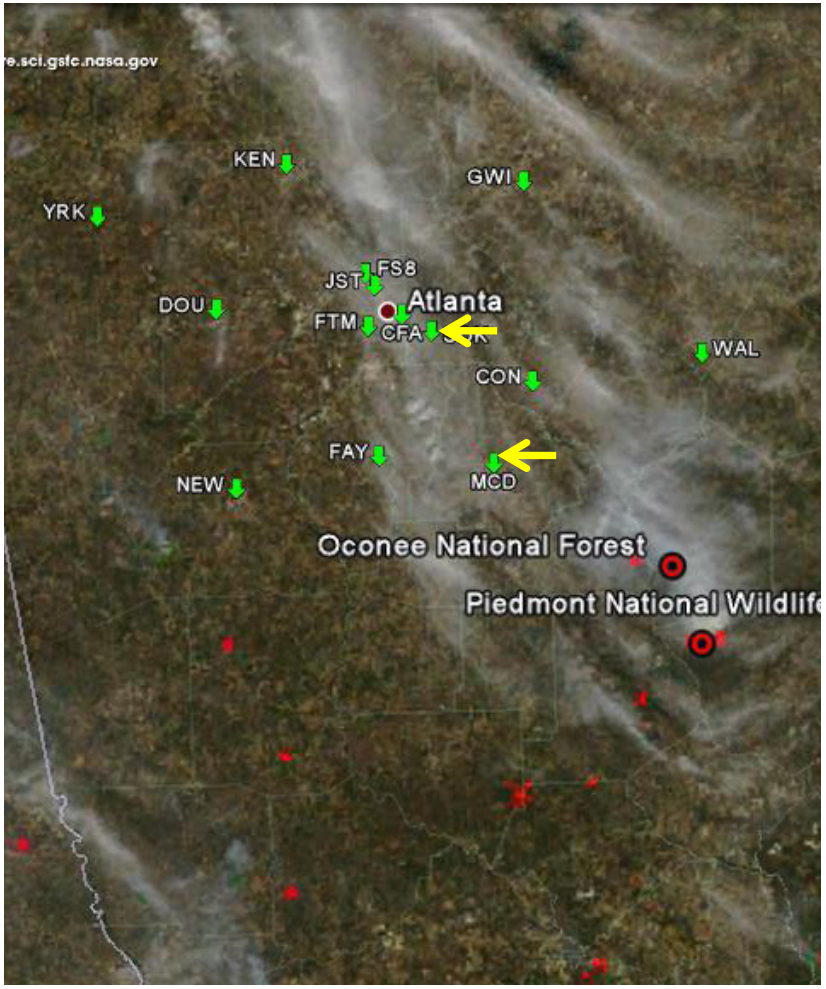

dc/ dE: Confederate Ave.
Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Layer 7
Layer 8
Layer 9
Layer 10
Layer 11
(µg/ m³) / ton
5
4
3
2
1
0
-1
15:00 17:00 19:00 21:00 23:00 1:00 3:00 5:00


Confederate Ave.
ΣS+BACKGROUND
BENCHMARK
µg/ m³
150
120
90
60
30
0
15:00 17:00 19:00 21:00 23:00 1:00 3:00 5:00

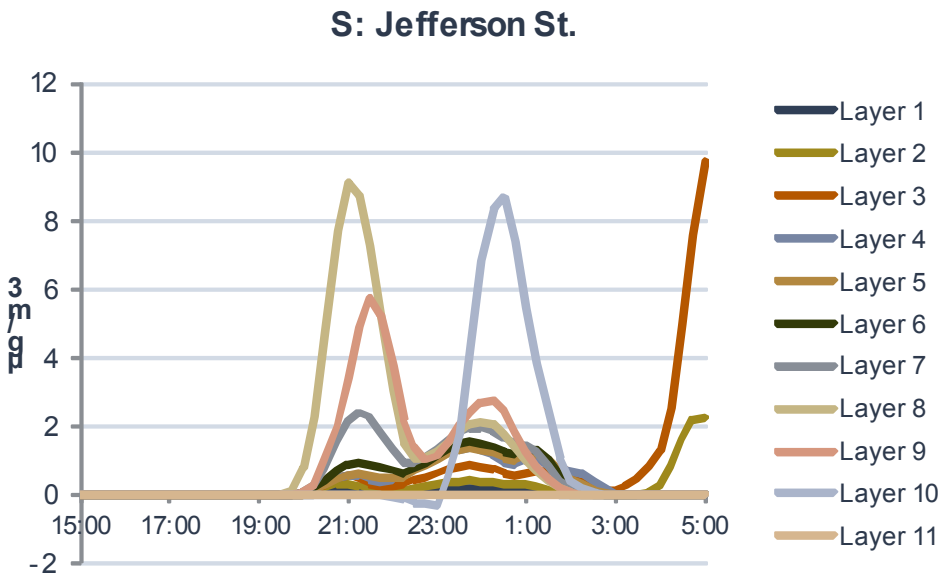
$S_{10\%}$ at McDonough, GA

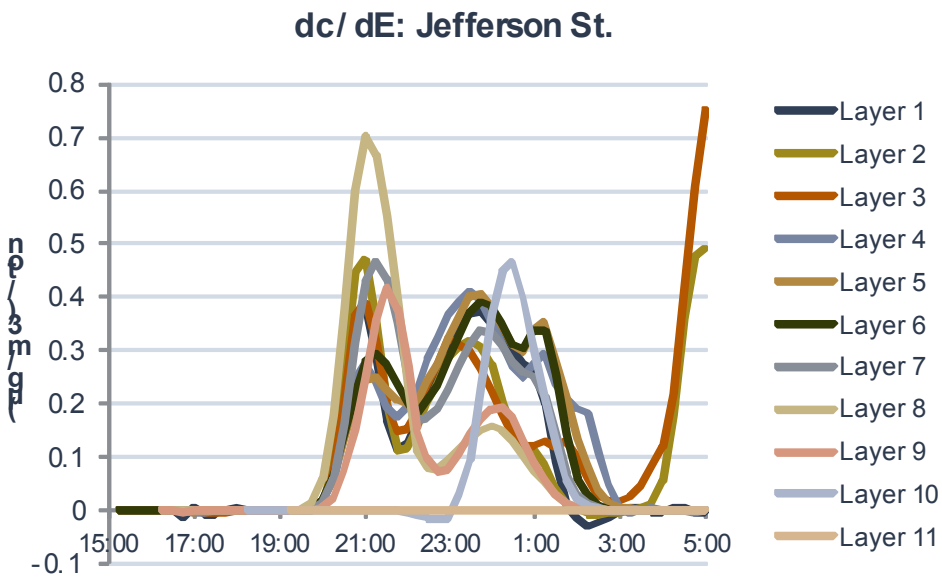


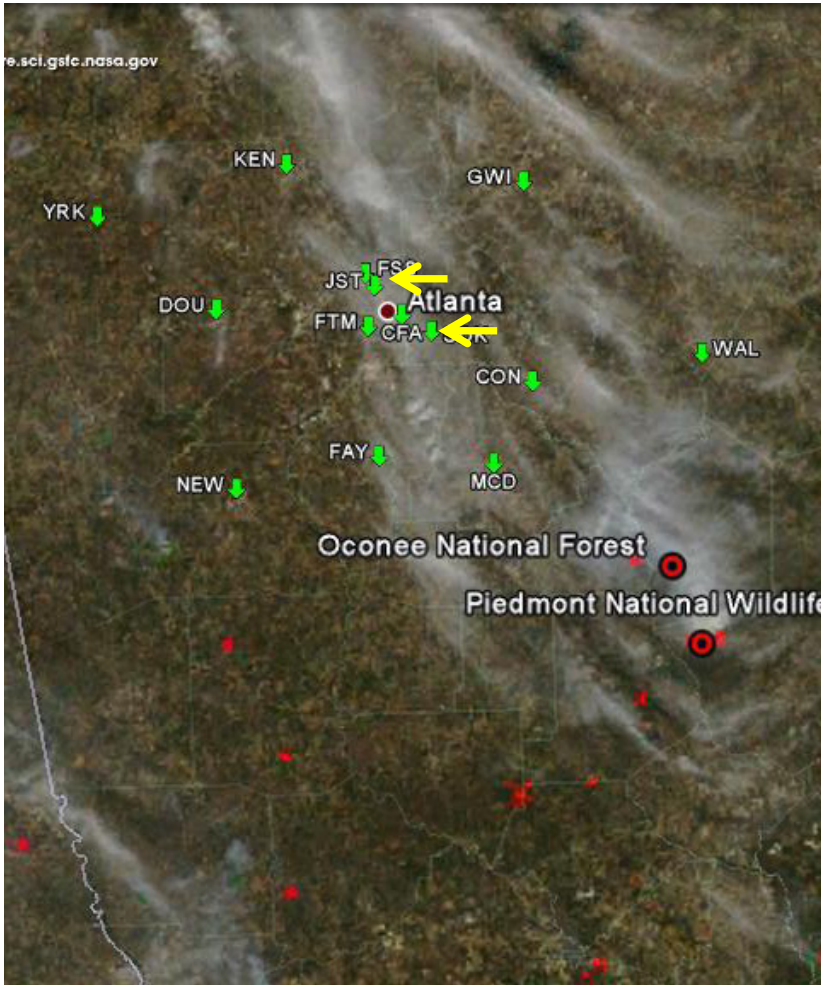




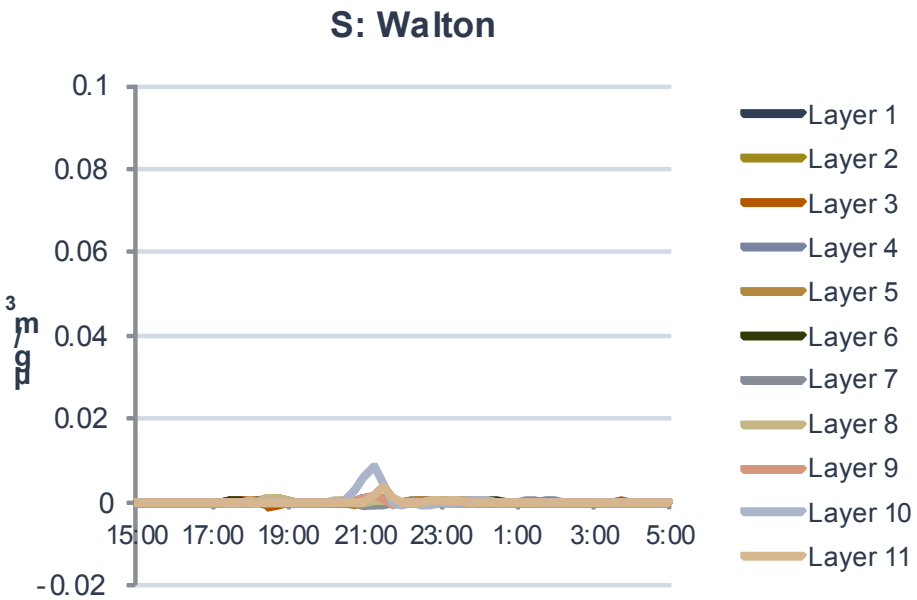
$S_{10\%}$ at Jefferson St.

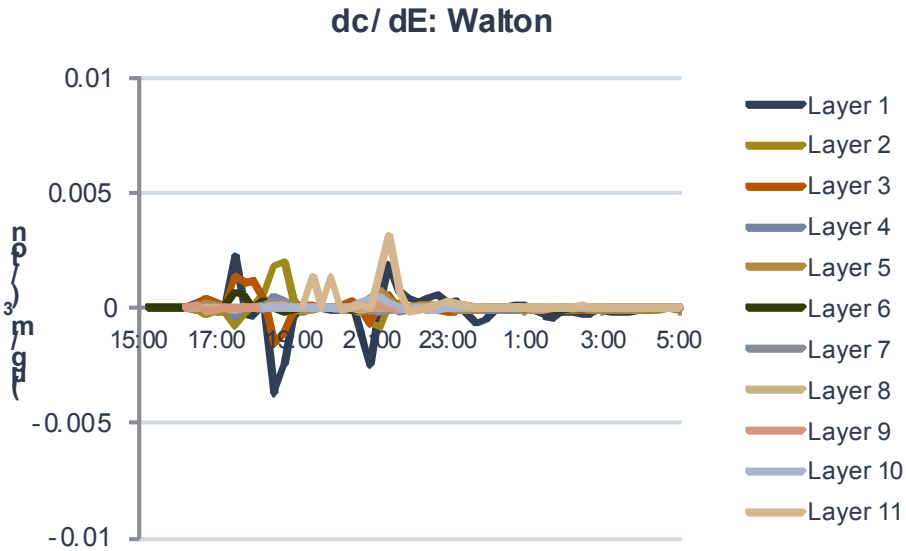


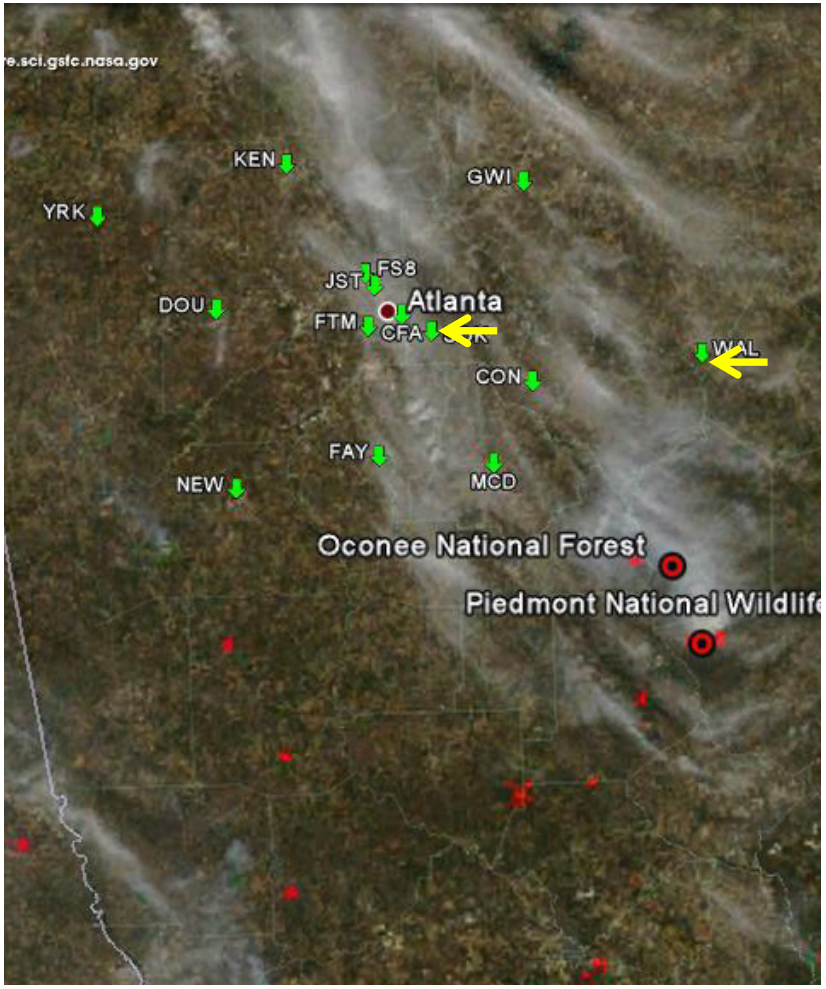




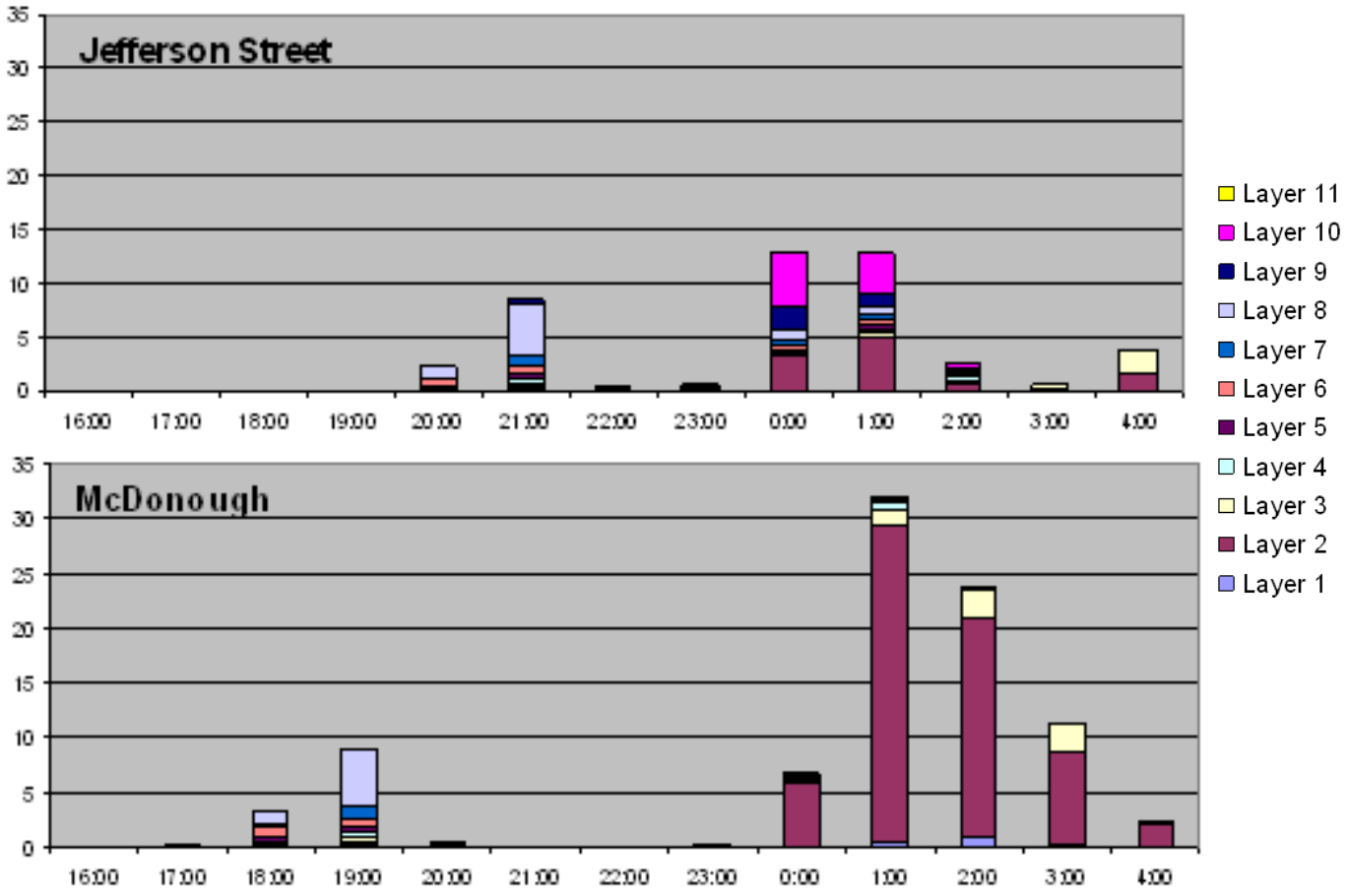
$S_{10\%}$ at Walton, GA







S from Direct Decoupled Method (CMAQ-DDM-3D)



Conclusions

- Vertical fire emissions distribution can play an important role in fire air quality modeling.
- Sufficient vertical model resolution could be important for successful fire modeling.
- Sensitivity analyses of vertical emissions layering can provide useful insight into fire simulations.
- 1st order sensitivities provide accurate results for small (~10%) perturbations in layered fire emissions of primary pollutants.
- Brute force estimates agree with DDM results.
- The sensitivities could be applied to improve model performance by optimizing vertical emissions profiles.

THANK YOU!

Questions?

Strategic Environmental Research and Development Program

Joint Fire Science Program

Georgia Department of Natural Resources, Environmental Protection Division

US Forest Service, Southern Research Station