Sensitivity of CMAQ Simulations to Prescribed Burn Emissions under Varied Plume Core Numbers

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Outline

- Multiple cores of smoke plumes:

  A feature of Daysmoke

- Sensitivity analysis of Daysmoke
- Impacts on CMAQ simulations:

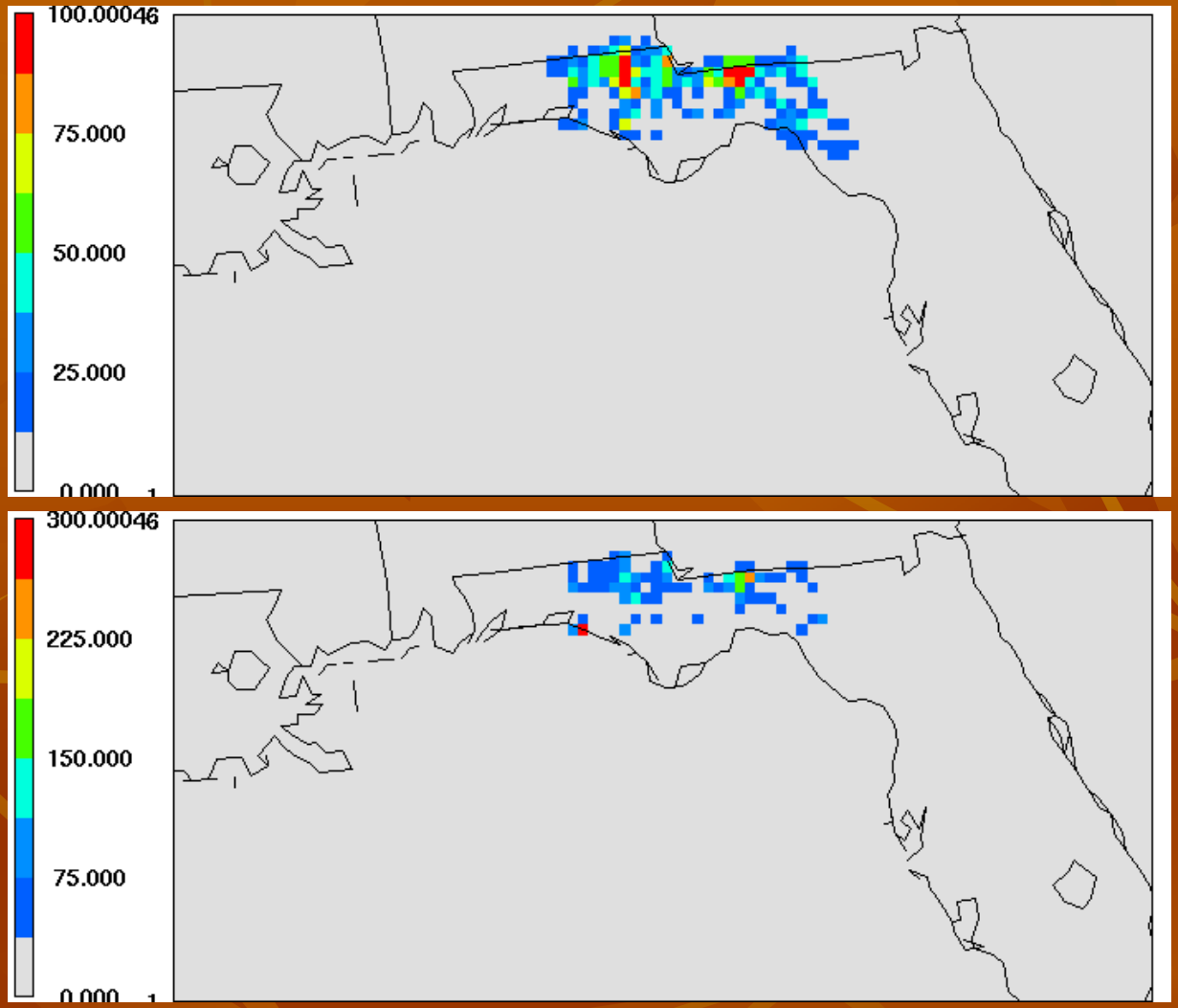
  Brush Creek burn

- Summary and Conclusions

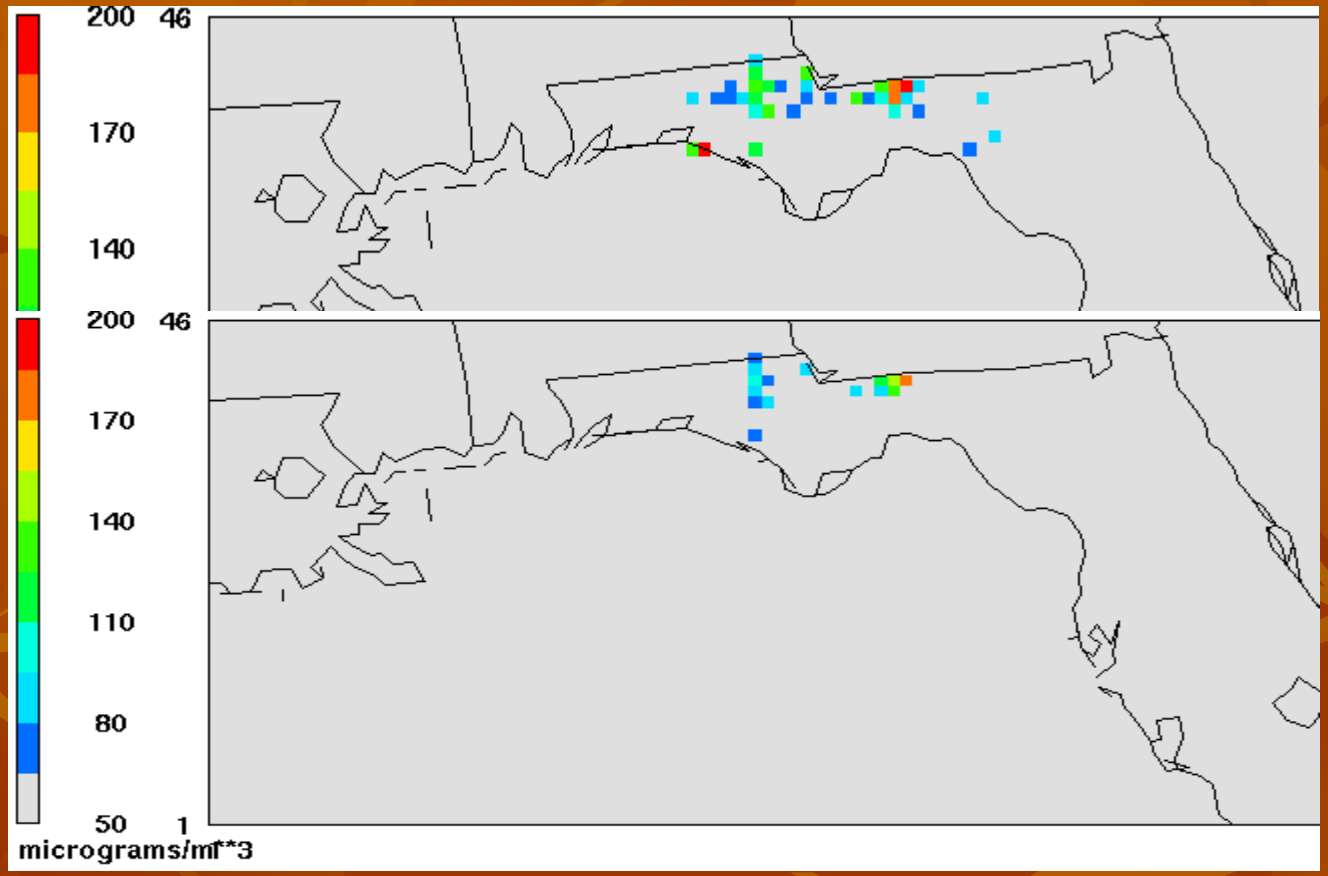
Emissions from Forest Fire

- Elevated emission source
- Plume rise and vertical profile are needed for air quality models

Point vs Area Source



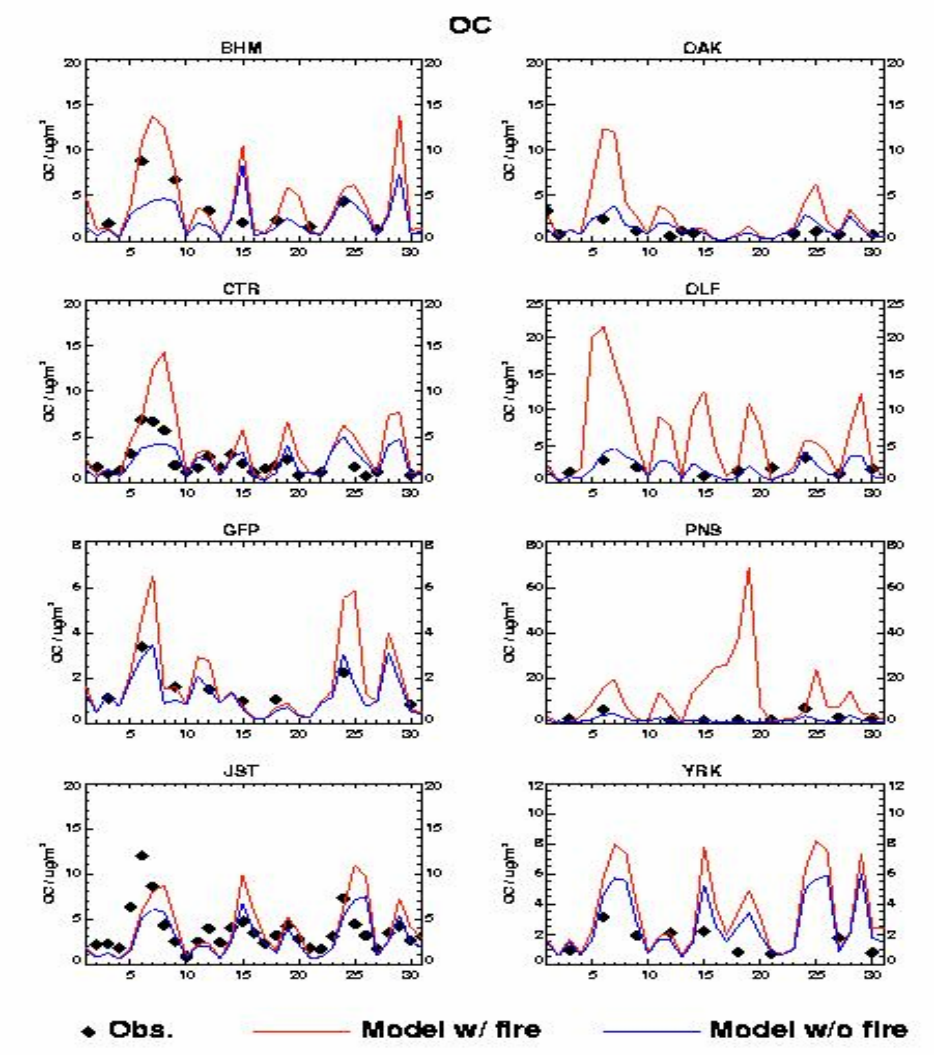
Air quality effects in burn areas are reduced as point source



Air quality effects in burn areas are reduced as point source

Simulation with VISTAS Data
(Fire as an Area Source)

March 2002



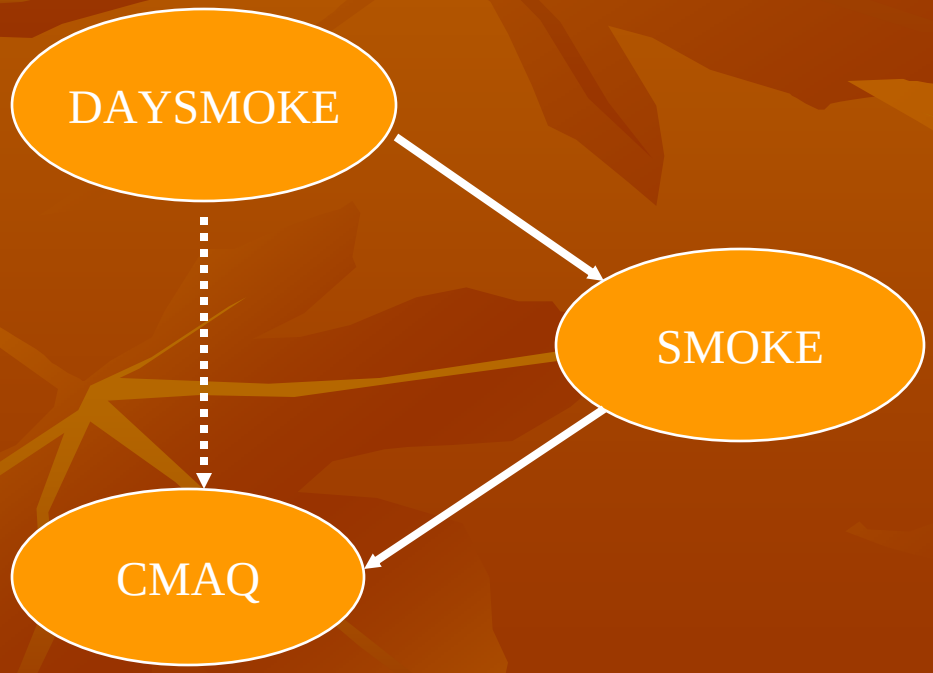
Over-prediction of ground concentrations at most sites

(from Wang et al.)

Daysmoke

- Developed from an ash dispersion and deposition model for sugar cane burn (Achtemeier 1998)
- A smoke particle transport and dispersion model
- A smoke injection scheme for air quality models

Daysmoke

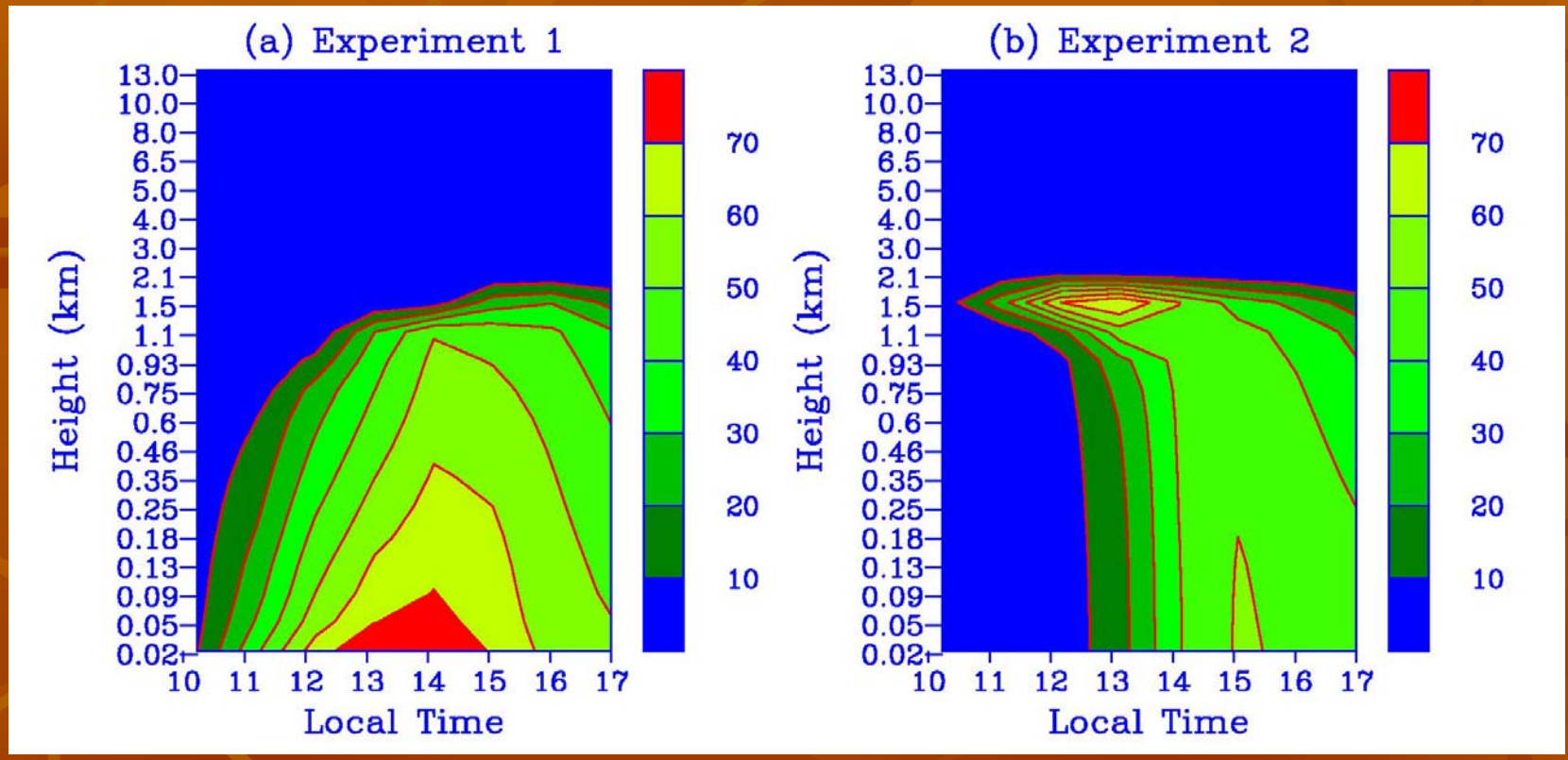


A unique feature with SHRMC-4S is coupling of Daysmoke.

A smoke particle transport and dispersion model

A fire plume rise scheme for air quality models

A Problem with CMAQ-Daysmoke Simulation of Fire Emissions

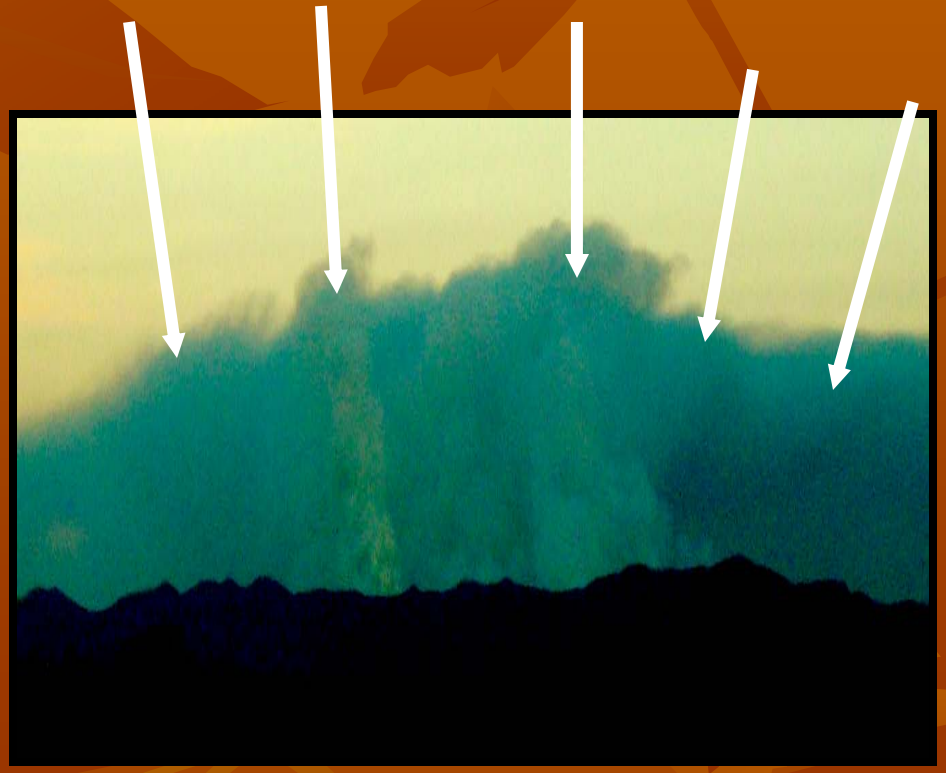


Emission as area source

Emission as point source with Daysmoke

Time-height cross section of $PM_{2.5}$ concentration ($\mu g\ m^{-3}$)

Multiple-core Updraft of Smoke Plume: A Possible Solution?



Research Issues on Multiple-core Updraft

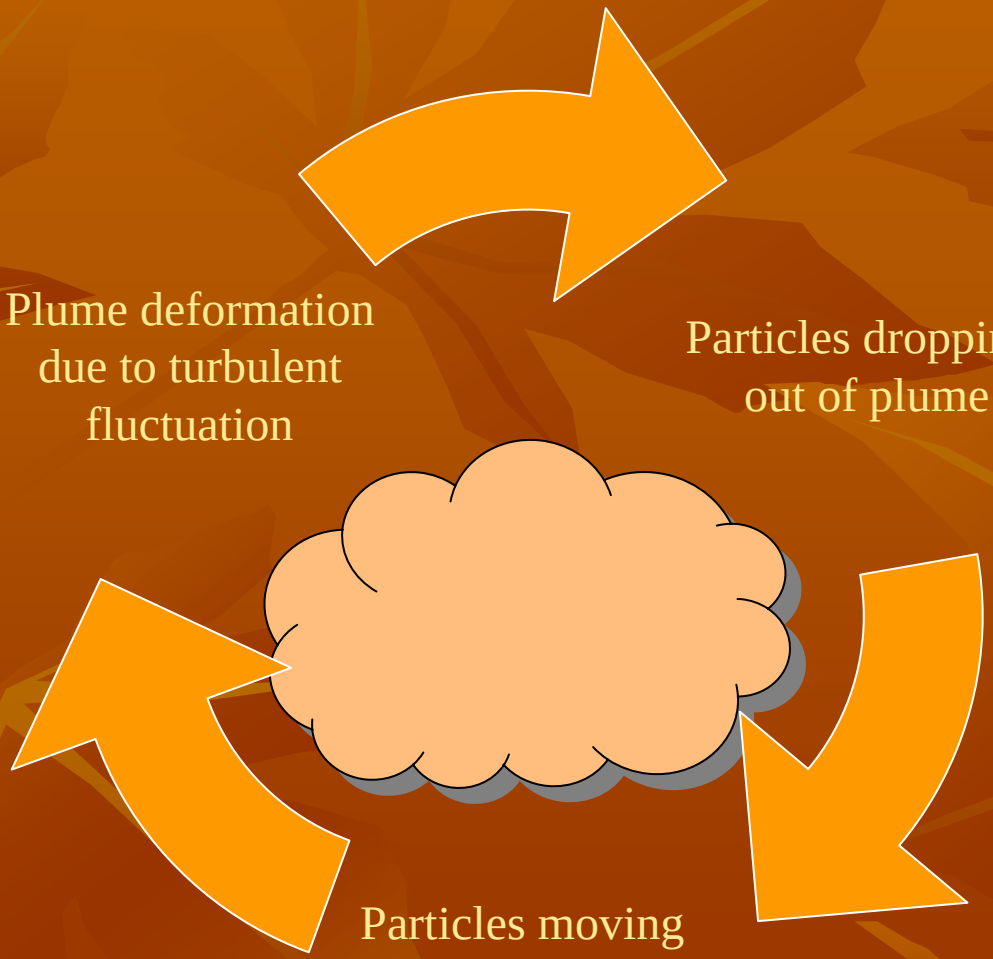
- Description of multiple-core plumes in Daysmoke
- Importance relative to other properties
- Impacts on Daysmoke simulation

  Gary Achtemeier et al.

- Impacts on CMAQ-Daysmoke simulation

  This presentation

Processes



Plume deformation due to turbulent fluctuation

Particles dropping out of plume

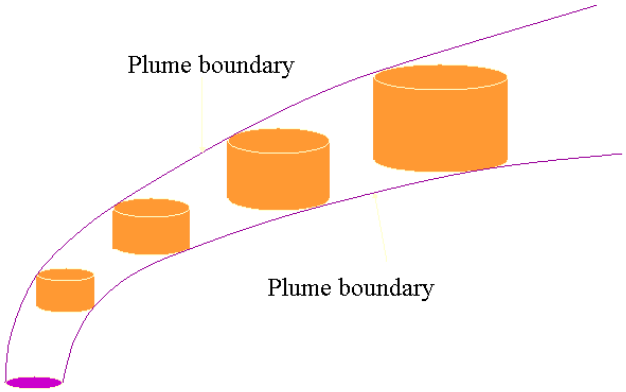
Plume rise

Vertical profile

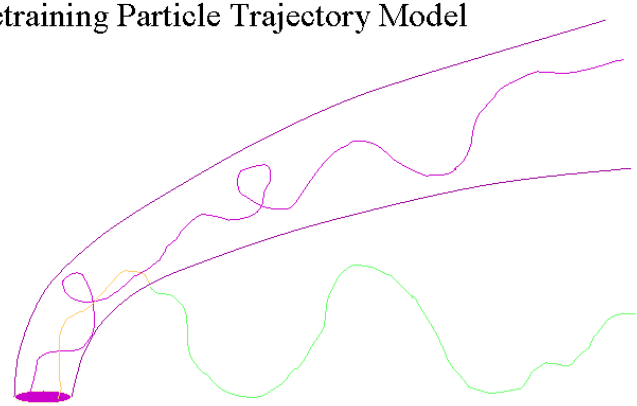
Particles moving up with plume

Components of Daysmoke

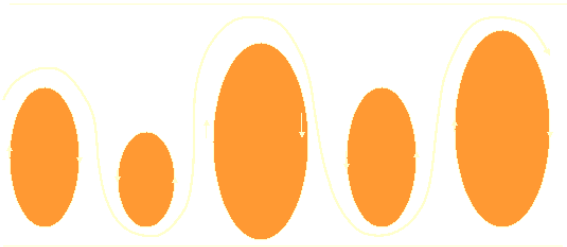
Entraining turret model

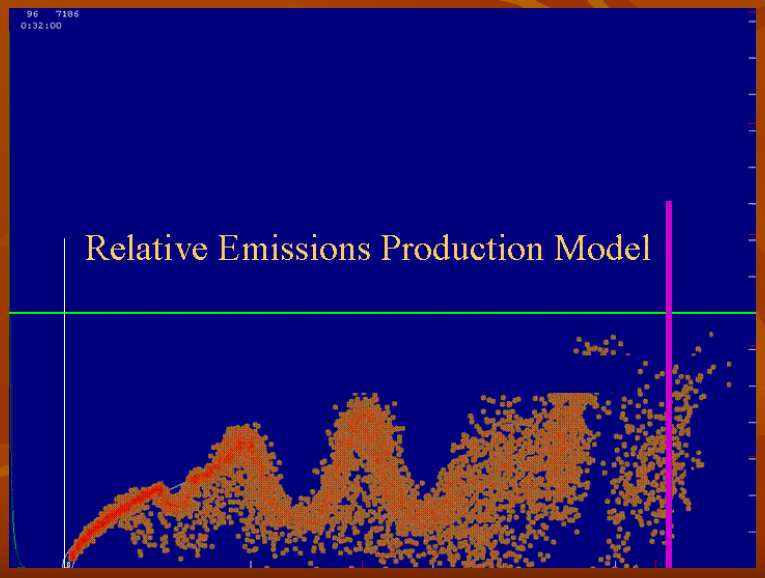


Detraining Particle Trajectory Model



Large Eddy Parameterization





Description of Daysmoke

Model	Function	Major Process	Factor
ETM	Boundaries	Buoyancy	R_0 (D), w_0, ΔT_0
DPM	Displacement of particles	Momentum	U, u'_{turb}, u'_{LED}
LEP	Estimate u'_{LED}	Convection	U, h
REM	Emissions, initial values, plume rise	CONSUME EPM	Fuel and burn properties

Comparison with Briggs scheme

Scheme	Emission Source	Model Type	Feature Provided
Daysmoke	Fire	3D dynamic-stochastic	Plume rise Profile
Briggs	Stack	Static similarity relationship	Plume rise

Description of Multiple Cores in Daysmoke

$$D = [\, 4\, F / (\, c\, \pi\, n\,)\,]^{1/3}$$

D — effective plume diameter

n — the number of cores

F — volume flux

c — coefficient

The larger n, the smaller D,
the lower plume rise

Daysmoke Parameters

Parameter	Meaning	Range
Cp	Plume turbulence coefficient	0.05-0.2
Cu	Air horizontal turbulence coefficient	0.05-0.2
Cw	Air vertical turbulence coefficient	0.01-0.08
Kx	Thermal horizontal mixing rate	0.5-1.5
Kz	Thermal vertical mixing rate	0.5-1.5
Wc	Plume-to-environ. cutoff velocity	0.1-0.5
w*	Air induced ash downdraft velocity	0.0-0.01
Wr	Maximum rotor velocity	0.25-0.75
Pk	Entrainment coefficient for plume	0.05-0.25
W1	Initial plume vertical velocity	1.0-3.0
TD	Initial plume temperature anomaly	2.0-8.0
Fd	Diameter of flaming area	2.5-100.0
Tm	Surface temperature	75.0-85.0
Dm	Dew-point temperature	60.0-80.0
Wm	Surface wind	1.0-5.0

Sensitivity Experiment

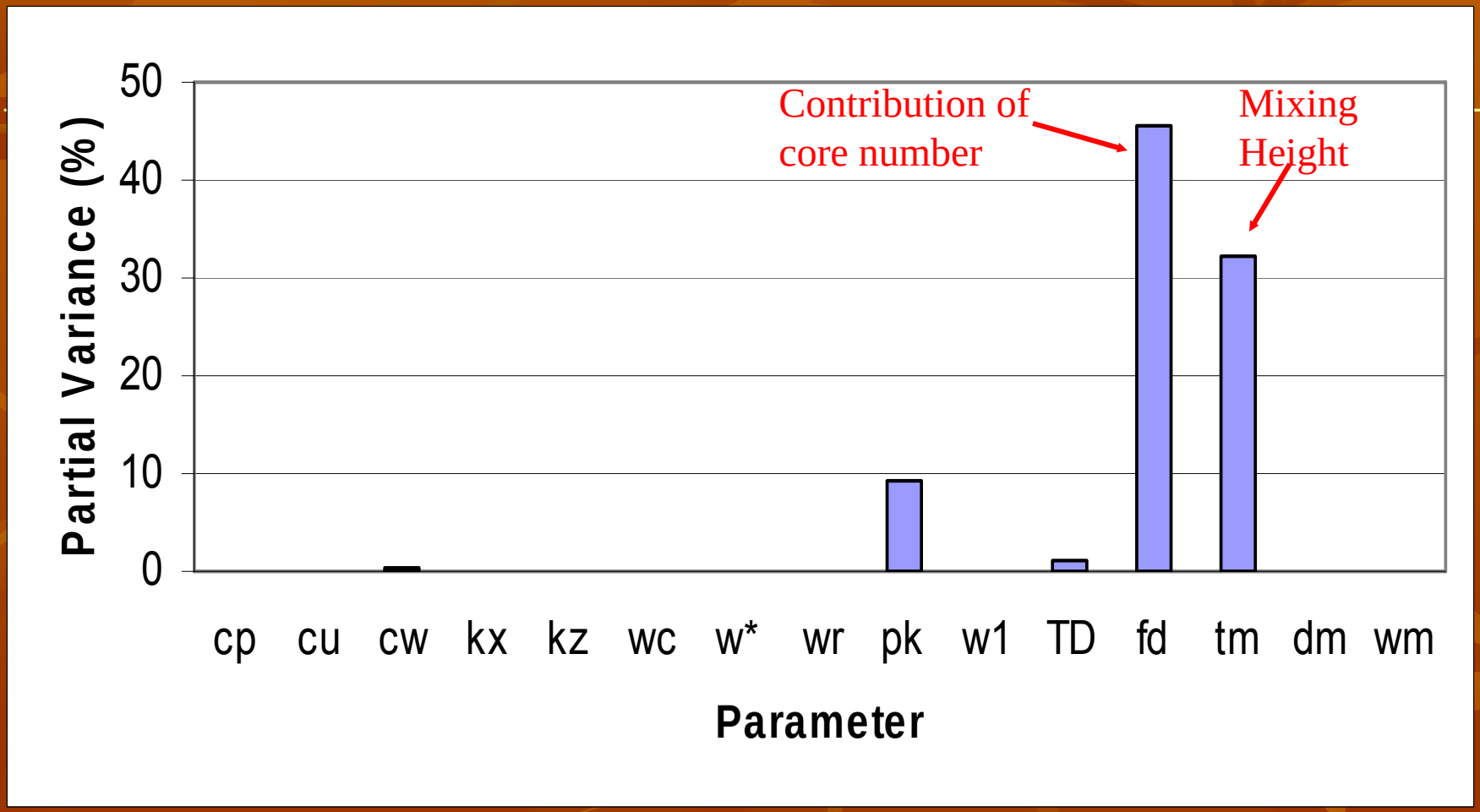
- Fourier Amplitude Sensitivity Test (FAST): identify which parameters mostly affect the plume rise in Daysmoke.

- Conditions: The input parameters, assumed to be mutually independent, are varied simultaneously through their ranges of possible values.

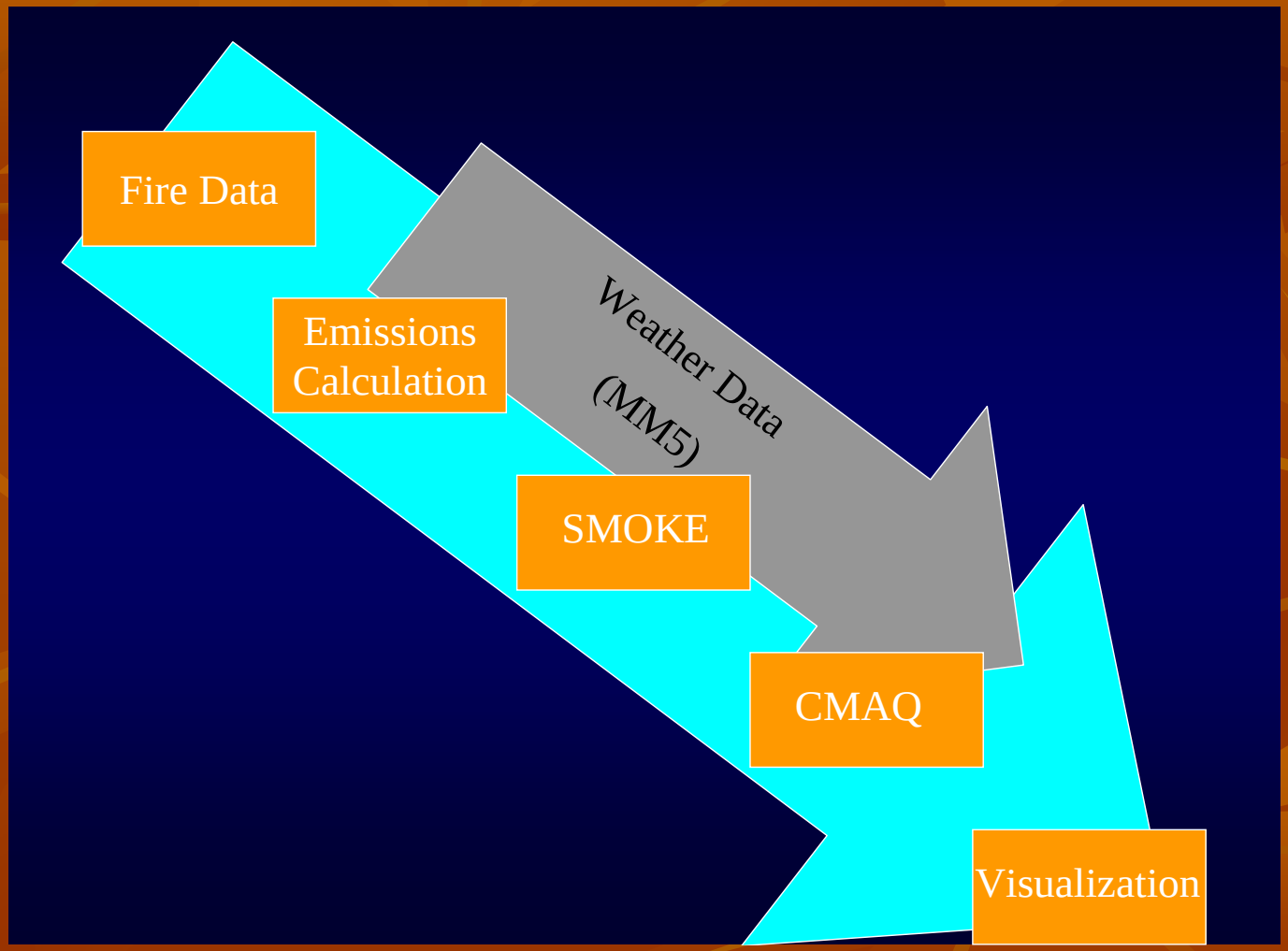
- Method: Partial variance of model output measures the uncertainty due to the variability of the input parameters.

- Advantage: 1027 runs for a model with 15 input parameters (10^{15} with a sampling technique for 10 values within the range of all input parameters)

Most Important Properties



How to Affect Air Quality Simulation



SHRMC-4S (Southern High-Resolution Modeling Consortium-Southern Smoke Simulation System)

CMAQ: a core component of SHRMC-4S

Examine Impacts with Brush Creek Burn Case

- Location

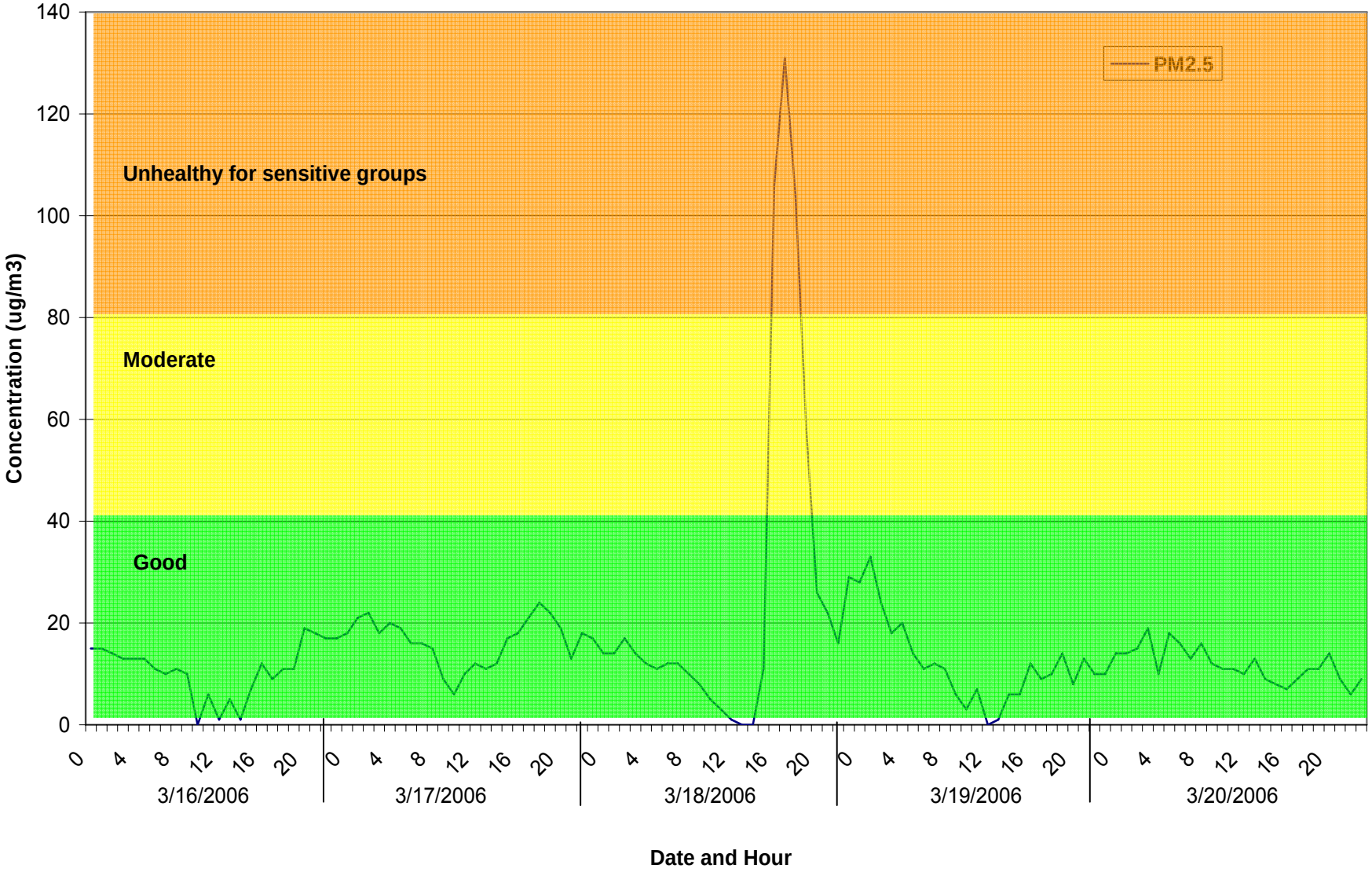
  Brush Creek unit of the Cherokee National Forest (near Tennessee -North Carolina border)

- Date: *March 18, 2006*
- Burned area: *1656 acres*

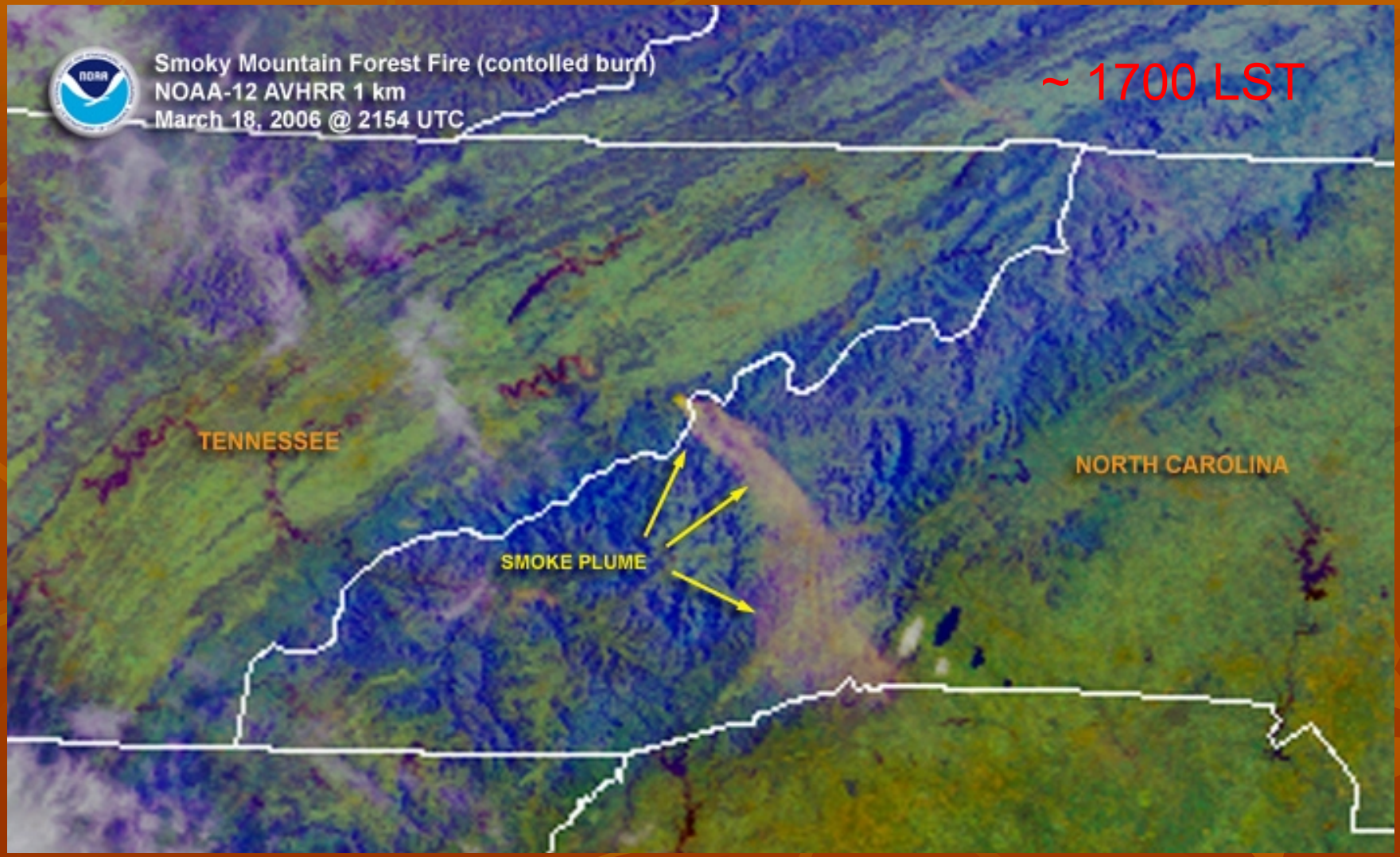
CMAQ Simulation

- Resolution: *12 km*
- Vertical layer: *21*
- Meteorology: *MM5*
- Emission: *Consume and EPM*
- Chemical Mechanism: *Carbon Bond-IV*

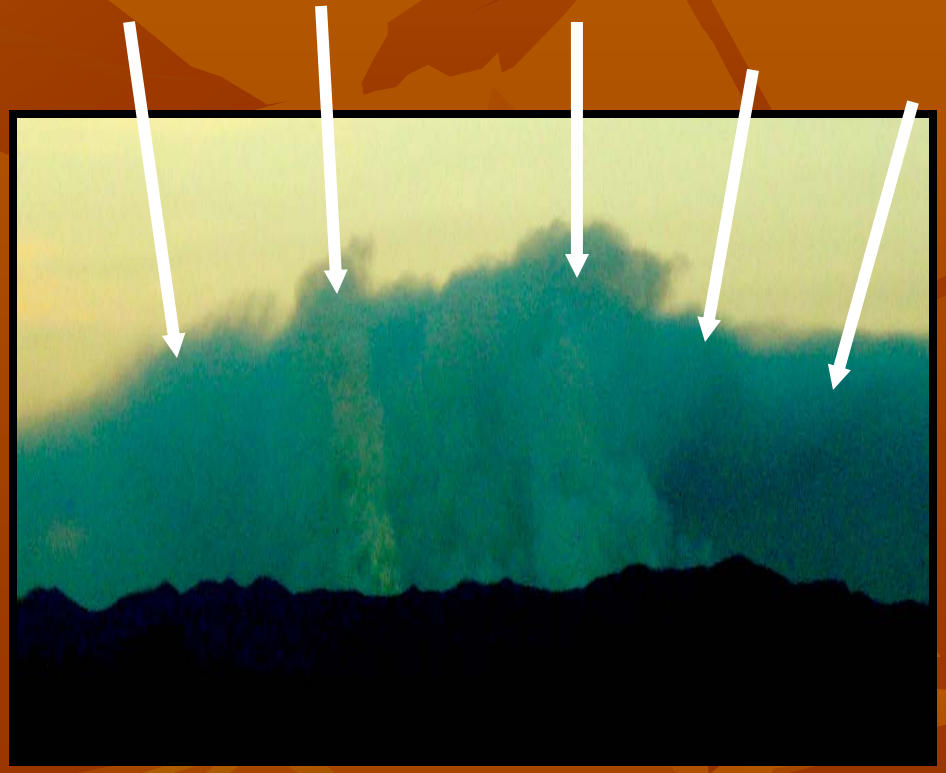
Asheville, North Carolina PM2.5 Concentrations



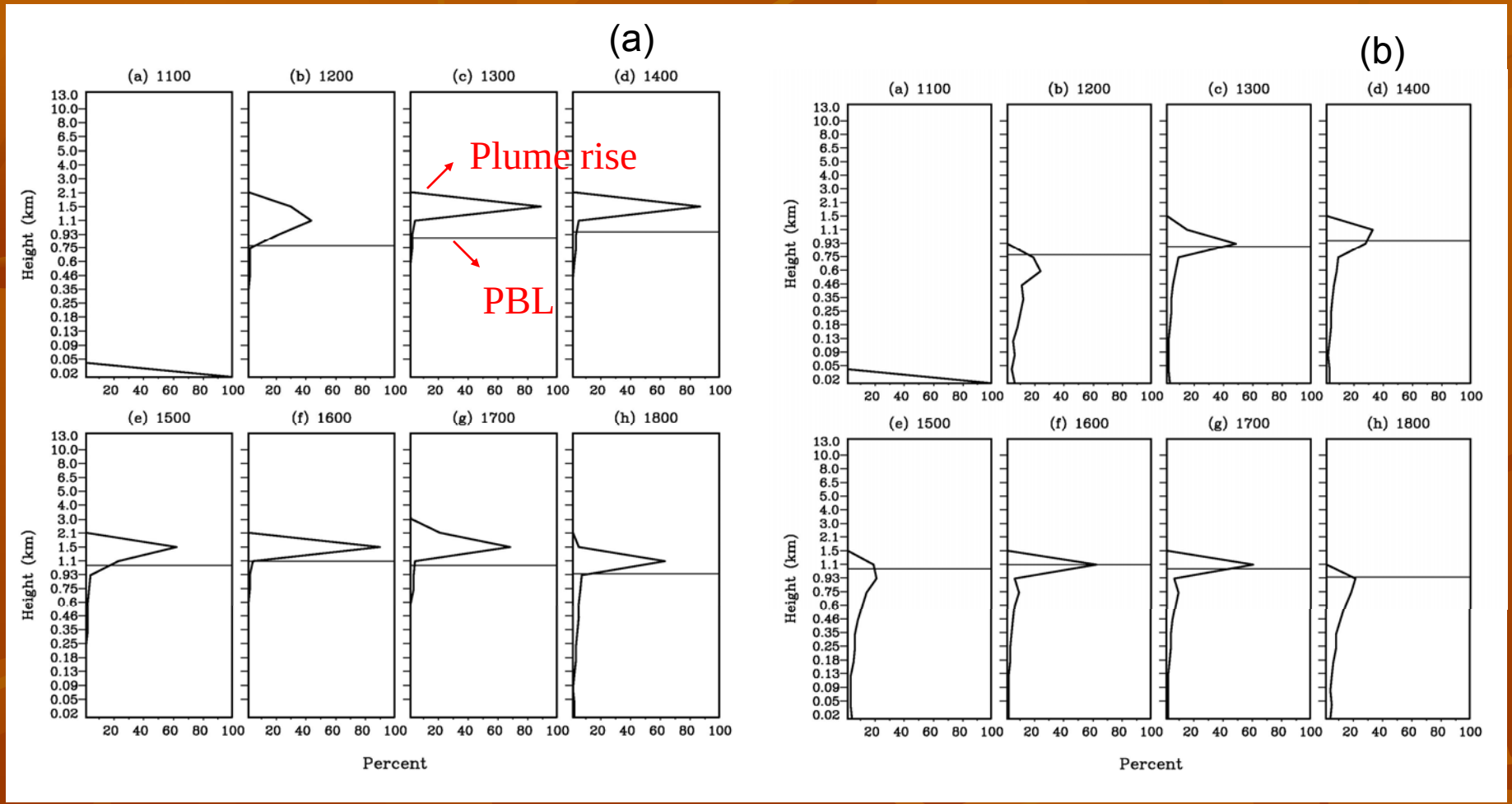
Satellite remote sensed smoke plume



Side View of the Brush Creek Burn



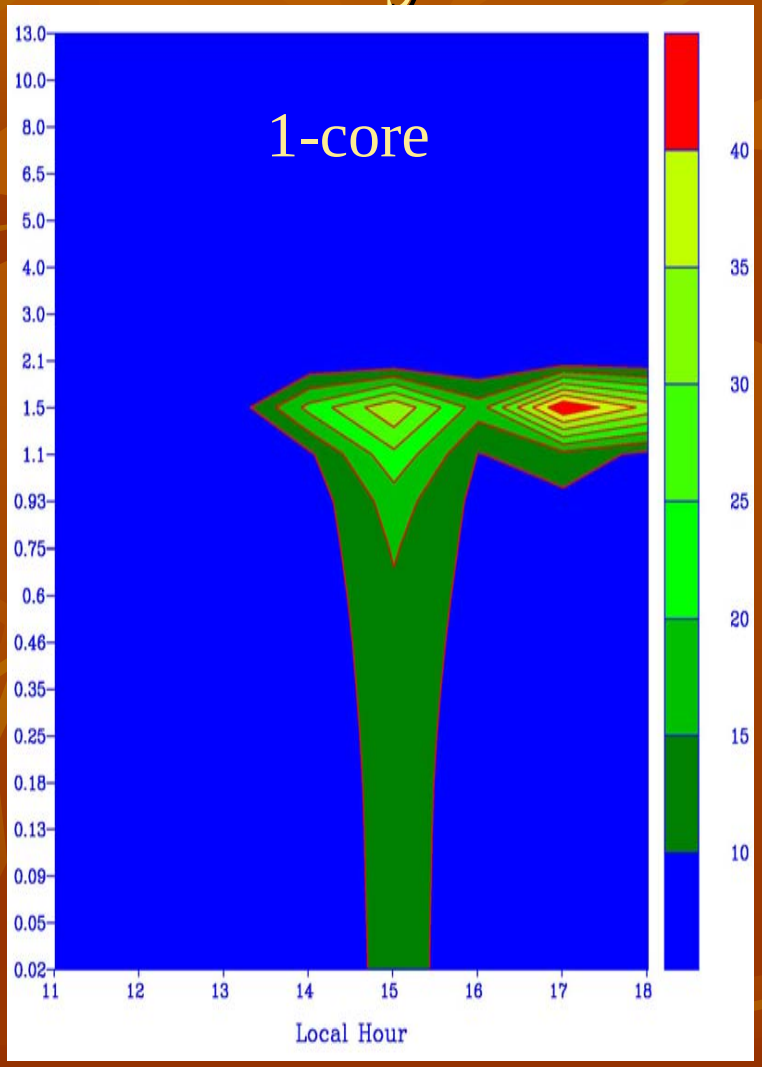
Plume Rise and Vertical Profile

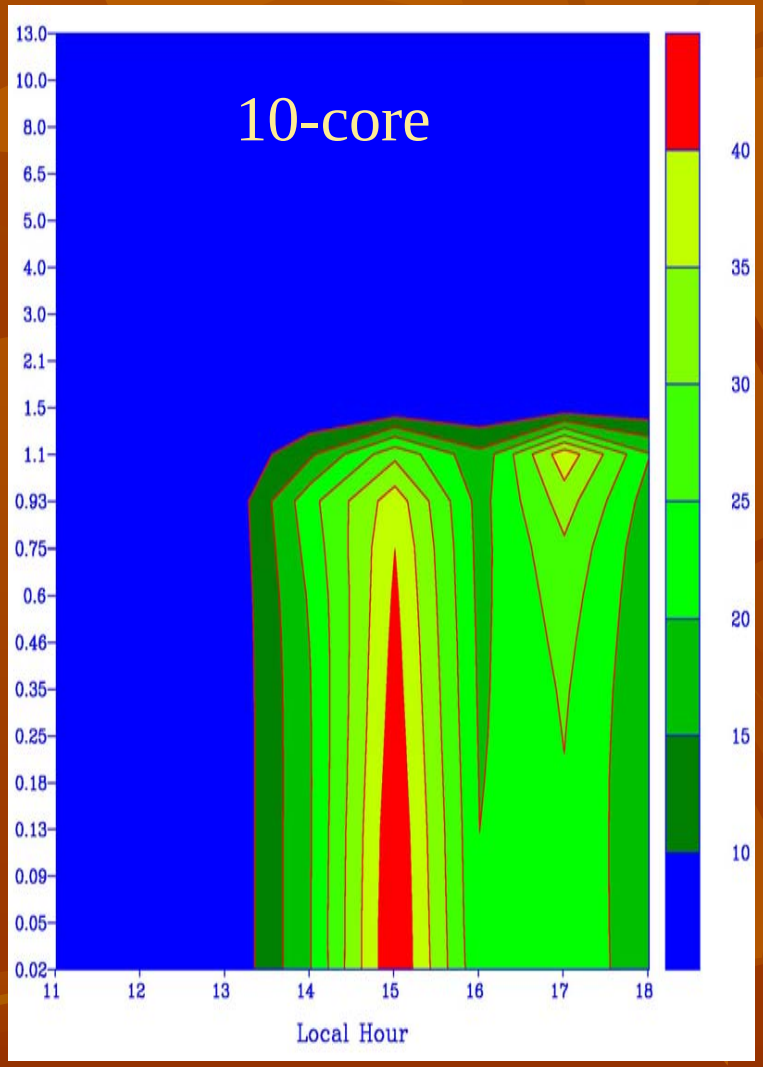


Single-core updraft

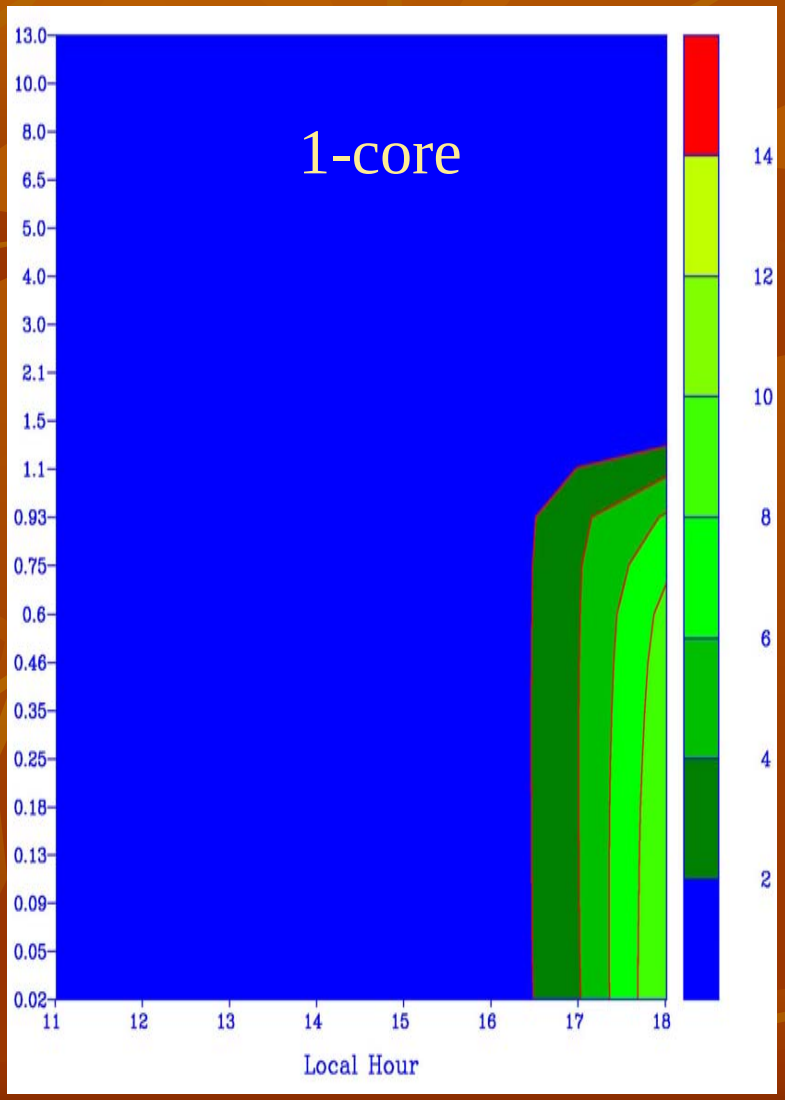
10 - core updraft

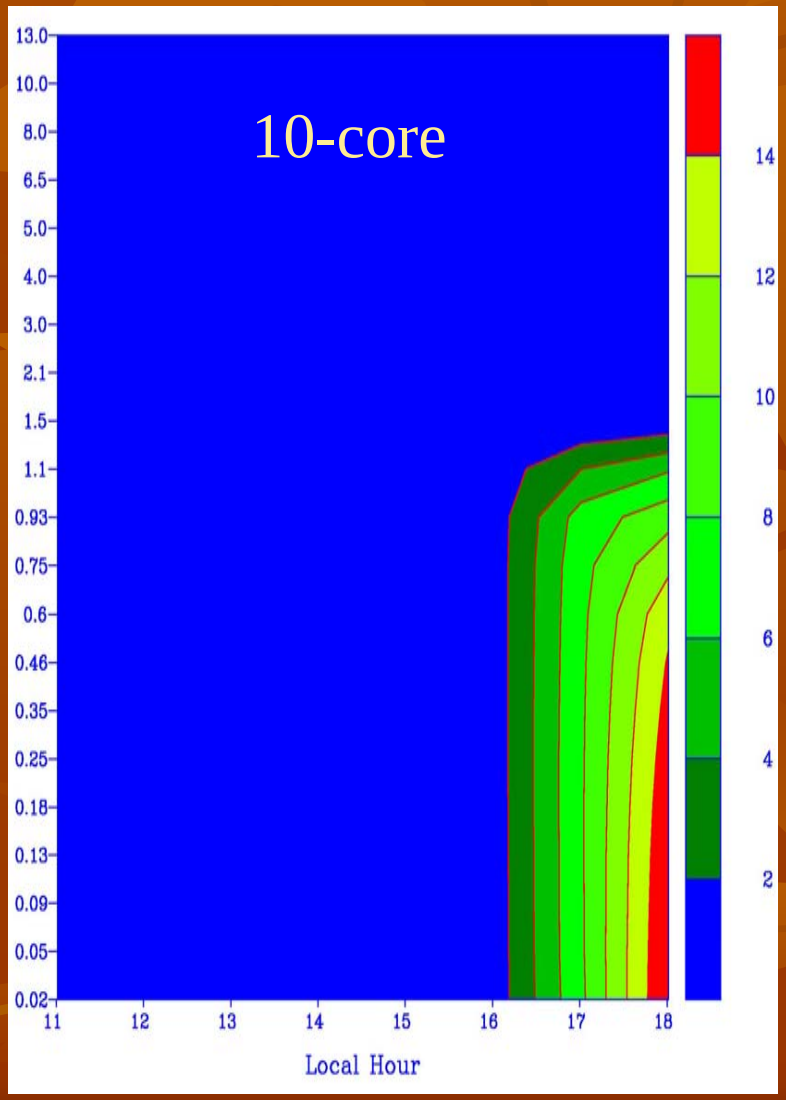
PM2.5 Concentration at Burn Site from Daysmoke



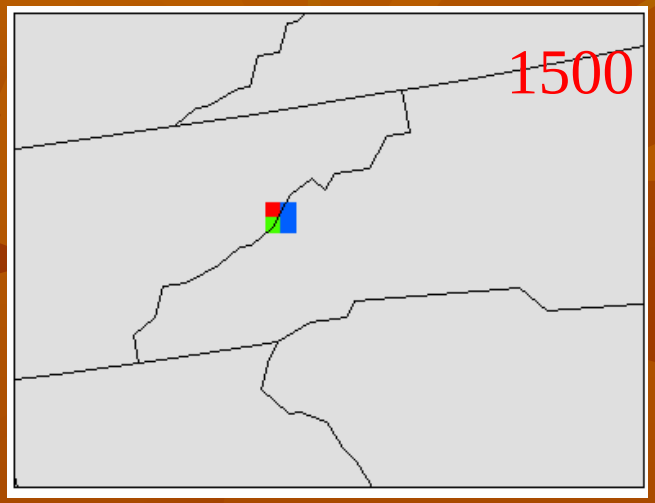


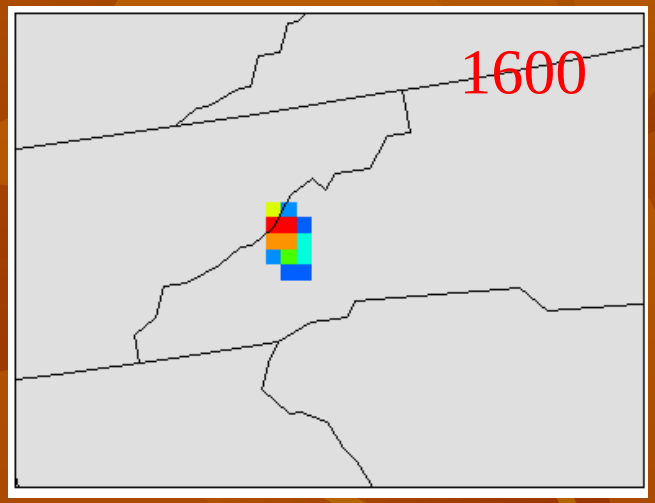
Downwind PM2.5 Concentration

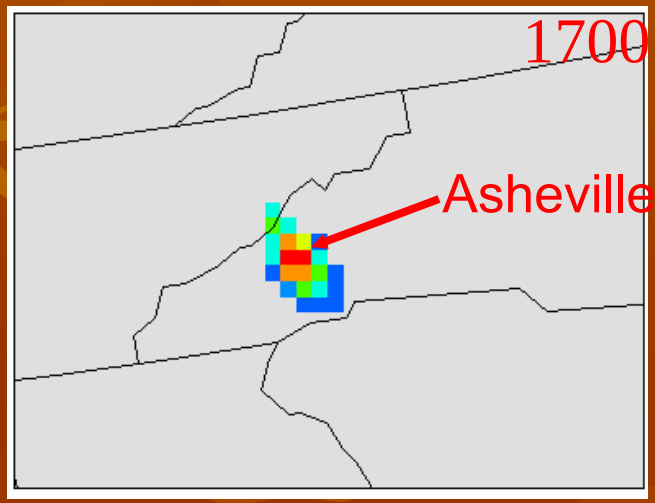


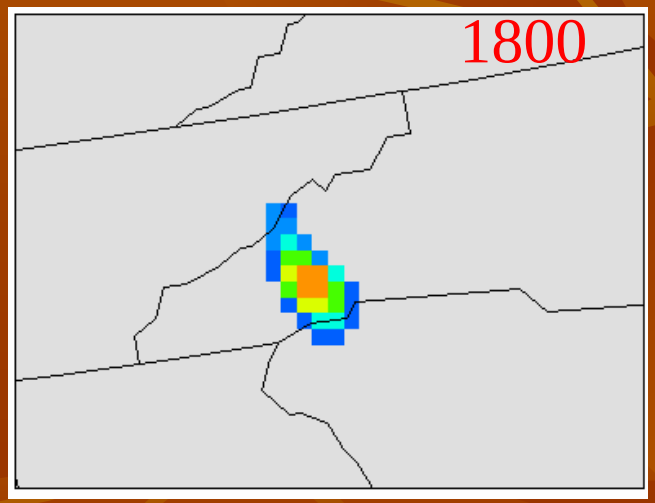


Simulated Plume (12-km resolution)









Red = 20 ug/m3


1500
1600
1700
1800
Red= 40
ug/m3

Summary

- A new smoke plume feature of multiple-core updraft is added in Daysmoke
- Unlike single-core updraft, Daysmoke ejects a large part of smoke particles within PBL for multiple-core updraft.
- Core number is most important factor for determining plume height
- CMAQ-Daysmoke obtains a much larger ground $PM_{2.5}$ concentration for multiple-core than single-core updraft, which is closer to the measurements.

Conclusion

The number of plume cores is an important factor. The problem is how to define the correct plume core numbers for CMAQ-Daysmoke simulations.

Acknowledgement

- Supports from the National Fire Plan, USDA Cooperative State Research, Education, and Extension Service (CSREES) Air Quality Program and EPA.
- Burn information from Florida Division of Forestry.
- Satellite images from William Jackson of Cherokee National Forest.

Thanks!