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
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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
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 moving up with plume
- Particles dropping out of plume
- Plume rise
  - Vertical profile
Components of Daysmoke

Entraining turret model

Detraining Particle Trajectory Model

Large Eddy Parameterization

Relative Emissions Production Model
<table>
<thead>
<tr>
<th>Model</th>
<th>Function</th>
<th>Major Process</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETM</td>
<td>Boundaries</td>
<td>Buoyancy</td>
<td>$R_0 \ (D), \ w_0, \ \Delta T_0$</td>
</tr>
<tr>
<td>DPM</td>
<td>Displacement of particles</td>
<td>Momentum</td>
<td>$U, \ u'<em>{turb}, \ u'</em>{LED}$</td>
</tr>
<tr>
<td>LEP</td>
<td>Estimate $u'_{LED}$</td>
<td>Convection</td>
<td>$U, \ h$</td>
</tr>
<tr>
<td>REM</td>
<td>Emissions, initial values, plume rise</td>
<td>CONSUME EPM</td>
<td>Fuel and burn properties</td>
</tr>
</tbody>
</table>
## Comparison with Briggs scheme

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Emission Source</th>
<th>Model Type</th>
<th>Feature Provided</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daysmoke</td>
<td>Fire</td>
<td>3D dynamic-stochastic</td>
<td>Plume rise</td>
</tr>
<tr>
<td>Briggs</td>
<td>Stack</td>
<td>Static similarity relationship</td>
<td>Plume rise</td>
</tr>
</tbody>
</table>

The table above provides a comparison between the Daysmoke and Briggs schemes, highlighting their model types and the features they provide.
Description of Multiple Cores in Daysmoke

\[ D = \left( \frac{4 F}{c \pi n} \right)^{1/3} \]

- \( D \) — 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

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

![Graph showing partial variance (%) for different parameters with labels for the x-axis (cw, kw, w*, w1, TD, tm, dm, wm) and y-axis (0 to 50). The graph highlights the contribution of core number and mixing height.](image-url)
How to Affect Air Quality Simulation

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

CMAQ: a core component of SHRMC-4S

- Fire Data
- Emissions Calculation
- Weather Data (MM5)
- SMOKE
- CMAQ
- Visualization
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

Date and Hour

Concentration (ug/m³)

- Good
- Moderate
- Unhealthy for sensitive groups
Satellite remote sensed smoke plume

~ 1700 LST
Side View of the Brush Creek Burn
Plume Rise and Vertical Profile

(a) 1100  (b) 1200  (c) 1300  (d) 1400

Plume rise

PBL

10 - core updraft
PM2.5 Concentration at Burn Site from Daysmoke
Downwind PM2.5 Concentration

1-core

10-core
Simulated Plume (12-km resolution)

1500

1600

Red = 20 ug/m3

1700

1800

Asheville
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

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