Fire emissions from North America: A Simple Modeling Approach

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Emissions from Fires

- Fire emissions impact air quality, visibility, and climate

- Emissions from fires can have local, regional and even continental impacts
  - transport from Central America, Mexico, Canada
Emissions from Fires

- Fire emissions impact air quality, visibility, and climate

- Emissions from fires can have local, regional and even continental impacts

Important to include fire emissions with regional and global chemical and climate models
Fire Emissions Modeling for North America

Goals

– Create a consistent framework for modelers to quickly and efficiently estimate fire emissions
– Create an inventory to be readily used by air quality modelers
  • Base years: 2002 - 2005

Specifications:

• High resolution (~ 1km, hourly-daily)
• Include all of North America...
  – 10°-71° N and 55°-175° W
• Include emissions from all fires
  – wildfires
  – prescribed fires
  – agriculture fires
Modeling Fire Emissions

\[ Emission_i = A \times B \times CE \times e_i \]

**A**: Area Burned

**B**: Biomass burned (biomass burned/area)
- type of vegetation (ecology)
- fuel characteristics:
  - amounts of woody biomass, leaf biomass, litter, ...
- fuel condition
  - moisture content

**CE**: Combustion Efficiency

**e_i**: Emission factor (mass emission_i /biomass burned)
- fuel characteristics
- fuel condition
- fire phase (flaming versus smoldering)
Fire Identification

- MODIS Thermal Anomalies Product
  - global coverage (~daily)
  - 1 km² pixels

- Available from several sources
  - University of Maryland/NASA
    http://maps.geog.umd.edu/default.asp
  - USFS Remote Sensing Application Center (RSAC)
    http://activefiremaps.fs.fed.us/fireptdata.php
  - NASA Earth Observing System Data Gateway
    http://delenn.gsfc.nasa.gov/~imswww/pub/imswelcome
Fuel Characterization

• Global Land Cover 2000 (GLC2000) coverage
  – based on SPOT Vegetation product
  – 1 km resolution
  – 29 vegetation classifications
    • temperate, tropical, and boreal vegetation distinguished
  – available at:
    http://www.gvm.sai.jrc.it/glc2000/
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- MODIS Vegetation Continuous Fields (VCF)
  - 500m resolution
  - percent forest, herbaceous, bare cover
  - Available from the Univ. of Maryland
    http://glcf.umiacs.umd.edu/data/modis/vcf/
Fuel Loading

• Each GLC classification assigned woody and herbaceous fuel loading
  – fuel loading values from literature
  – woody and herbaceous fractions
    • determined with Fuel Characteristic Classification System (FCCS; McKenzie et al.)
Assumptions

• Each fire identification is assumed to be individual fire
  Area = 1 km² - Fraction bare cover

• Default land cover classification assumed to be grasslands

• Combustion Efficiency based on amount of forest/herbaceous cover
  – (based on Ito and Penner, 2004)

• Emission factors from literature
Fire Emissions Estimation

• Created daily emissions inventory
  – Includes fires in all of North and Central America
    • 10°-71° N and 55°-175° W
  – Daily emissions for 2002 through 2005
  – Inventory includes emissions of:

  CO    PM$_{10}$
  CO$_2$ PM$_{2.5}$
  NO$_x$ CH$_4$
  NH$_3$ NMHCs
  SO$_2$
Annual Emission Estimates

PM2.5 Emissions (Tg/yr)

US

CAN

MEX

2002

2003

2004

2005
Emissions by Country

PM2.5 Emissions (Tg/yr)

United States, Canada, Mexico, Guatemala, Cuba, Nicaragua, Honduras, Venezuela, Dominican Republic, El Salvador, Costa Rica, Belize
Daily Emission Estimates

• Canada and U.S. have large emissions during summer wildfire season

• Mexican emissions during spring - brush clearing for agriculture

• U.S. has agriculture burning in spring and fall
Emissions by Land Cover Type

PM2.5 Emissions (Tg/yr)

- Mixed Fixed Forest
- Deciduous Forests
- Broadleaf Evergreen
- Needleleaf Evergreen
- Shrublands
- Grasslands
- Wetlands
- Croplands
- Other

* The total emissions from a single land cover category can vary by a factor of 2 from year to year
## Comparison with other estimates

<table>
<thead>
<tr>
<th>Study</th>
<th>CO Emissions (Tg yr(^{-1}))</th>
<th>Time Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hoezelmann et al.</td>
<td>31.61 – 42.81</td>
<td>• for 2000</td>
</tr>
<tr>
<td>[2004]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>van der Werf et al.</td>
<td>26.12 +/- 22.99</td>
<td>• for 1997-2001 +/- standard deviation</td>
</tr>
<tr>
<td>[2003; 2004]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>This Study</td>
<td>32.54 +/- 8.19</td>
<td>• for 2002-2005 +/- standard deviation</td>
</tr>
</tbody>
</table>
Comparison with NEI values reported 07/2005
Uncertainties

- Fire detections
  - missed fires due to cloud cover or overpass timing
    - missing prescribed/agriculture fires?
  - double detections from 2 satellites
  - “bow tie” effect (location within swath)
Uncertainties

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• Area Burned

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<th>Fire</th>
<th>Location</th>
<th>This Study</th>
<th>BLM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cedar Fire</td>
<td>Southern California</td>
<td>275,750</td>
<td>281,000</td>
</tr>
<tr>
<td>Aspen fire</td>
<td>Arizona</td>
<td>59,500</td>
<td>164,000</td>
</tr>
<tr>
<td>Paradise Fire</td>
<td>Southern California</td>
<td>103,000</td>
<td>56,700</td>
</tr>
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Uncertainties

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• Area Burned

• Fuel Loadings
Uncertainties

• Uncertainties associated with Fuel Loadings

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<tr>
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<th>This Study (GLC2000)</th>
<th>FCCS</th>
<th>MODIS</th>
<th>NFDRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM2.5 Emissions (Tg/yr)</td>
<td>1.7</td>
<td>1.9</td>
<td>2.2</td>
<td>0.8</td>
</tr>
</tbody>
</table>
Uncertainties

• Fire detections
  – missed fires due to cloud cover or overpass timing
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• Area Burned
• Fuel Loadings
• Fuel characteristics
Emissions used within the CMAQ framework

• Estimated emissions for July 2001

• Speciated emissions to SAPRC99 mechanism
  – VOCs based on land cover burned and reactivity (S. Nandi)
  – PM by WRAP method

• Applied hourly emissions based on EPA documentation

• Converted to IO/API format and merged with other emissions
  – All emissions in surface layer

• Ran CMAQ for July 2001 with emissions
  – 36 km continental domain
Fires in CMAQ

Spatial distribution of Fire Emissions assigned to 36 km domain in July 2001
Aerosol from fires

- Hourly modeled PM$_{2.5}$ concentrations increased by as much as 36 μg m$^{-3}$
  - hourly organic aerosol fractions changed as much as 90%
  - monthly organic aerosol fractions changed as much as 11%

![Map of aerosol concentrations in July 2001](image-url)
Future Work

• Develop diurnal profiles for fire emissions
  – using WF_ABBA product (with Chris Schmidt, U. Wisc.)

• Develop parameterization for plume rise

• Incorporate other satellite data
  – fire detections (i.e., WF_ABBA)
  – fuel loadings (i.e., MODIS-derived, Zhang)
  – fuel conditions (i.e., NOAA VHI)

• Model Evaluation

• Forecast Modeling
  – MIRAGE and INTEX-B
Conclusions

• Simple fire emissions model has been developed
  – Provides modelers a quick way to include fires within simulations

• Emissions for 2002-2005 available
  – estimates compare well with other published values
  – estimates can impact air quality modeling results

• More work is needed
EXTRAS
Inconsistencies with available data
Uncertainties

- Uncertainties associated with Fuel Loadings

![Bar chart showing CO emissions (Tg/yr) for different sources: This Study (GLC2000), FCCS, MODIS, NFDRS. The MODIS emissions are the highest among the four sources.](chart.png)