Satellite-Based Estimates of Cropland Burning and Related Emissions: Results from the Contiguous United States and the Russian Federation

Jessica McCarty, Ph.D.
Dept. of Geography & Geosciences
University of Louisville
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Rationale for the study: Contiguous U.S.

• Agricultural and Rangeland Biomass Burning Emissions

• Air Quality
  – Health and Safety Issues
    • Cardiopulmonary diseases
    • Visibility
  – CO, SO₂, NO₂, PM₂.₅, PM₁₀
    • National Ambient Air Quality Standards (NAAQS)

• Climate Change
  – CO₂, CO, CH₄
    • North American Carbon Program (NACP)

• Carbon Budget
  – Integrate into existing carbon models for wildland fire
Rationale: Russian Federation

• Agricultural Biomass Burning Emissions
• Black Carbon
  – Arctic highly sensitive to short-lived climate forcers (SLFs); black carbon
  – Black carbon may account for 30% of Arctic warming
  – Ag fires occur during Arctic spring – when ice/snow melting

• Regulations have poor enforcement
  – Crop residue burning is technically illegal
  – Monitoring systems are ground-based

Smoke from field burning in distance in eastern Russia (Clean Air Task Force)
Definitions

- **Croplands**
  - Established crop areas that produce food, fiber, and seeds
  - Fallow fields
- **CONUS**: Bluegrass, Corn, Cotton, Rice, Soy, Sugarcane, Wheat, Other/Fallow
- **Russia**: Wheat, Canola, Sugarbeets, Other/Fallow

- **Crop Residue Burning**:
  1. Post-harvest or pre-planting burning for removal of ground-level senescent vegetation;
  2. Pre-harvest burning for removal of leaves and other biomass (sugarcane).
Definitions

- Rangelands
  - Predominantly grassland ecosystems that are managed for use as range, i.e., for livestock and/or native grazing species

- Reliance on RS land cover datasets; focus on grasslands

- CONUS: Short and tallgrass prairies, sagebrush, mesquite, invasive species

Rangeland Burning:

1. Pre-grazing burning to stimulate seeding;
2. Post-grazing burning for invasive species control/seeding.

Flint Hills in Kansas (Lawrence Journal-World)
Focus: Crop Residue Burning in CONUS
Research Design

Hybrid Cropland Burned Area Approach

Development of Regional Thresholds

Crop Residue Burned Area

Crop Type Mapping of CONUS

Emission factors

Fuel Load

Combustion completeness

Bottom-up Emission Estimates:

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

(Seiler and Crutzen, 1980)

- \( A \) = burned area
- \( B \) = fuel load
- \( CE \) = combustion efficiency
- \( e_i \) = emission factor

Seasonal and Interannual Variability of Emissions From Crop Residue Burning in CONUS
**Cropland Burned Area**

Hybrid approach (McCarty et al., 2008)
- Difference Normalized Burned Area (dNBR)
  \[ \text{NBR} = \frac{\text{band2} - \text{band7}}{\text{band2} + \text{band7}} \]
  - 500 m MODIS 8-day surface reflectance (MOD09A1)
    - \( \sim 2.1 \mu m \) range (band 7)
- Regional thresholds development *in-situ* data and high resolution burn scar maps
  - High resolution data (ASTER and Landsat)
  - GPS data from field campaigns
- Average burned area for active fire detections
  - 1 km MODIS Active Fire/Thermal Anomalies (MOD14)
    - Detect fires as small as 100 m\(^2\) (Giglio et al., 2003)
- Combine remotely sensed burned area estimates with active fire detections
- Validation with *in-situ* data and high resolution burn scar maps
On average, 1,239,000 ha of crop residue burned annually (McCarty et al., 2009).

Thirteen states contained 80% of total cropland burning (75,875 ha annually) – Florida, Arkansas, Idaho, California, Texas, Washington, Kansas, North Dakota, Colorado, South Dakota, Louisiana, Oklahoma, and Oregon.

Harvested area from USDA statistics – ~13% of total harvested area for crops that burn ~1% of total harvested area in CONUS burned annually – ~34% of harvested agricultural areas in Florida.
Comparison with Wildland Burned Area

• National Interagency Fire Center
  – Burned area of wildland fires for 50 states (average area)
  – CONUS crop residue burning ≈ 43% of total wildland burned area

<table>
<thead>
<tr>
<th>Year</th>
<th>Wildland burned area (ha)</th>
<th>Cropland burned area (ha)</th>
<th>% Cropland burned area</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>1,623,945</td>
<td>1,276,310</td>
<td>78.59%</td>
</tr>
<tr>
<td>2004</td>
<td>3,320,131</td>
<td>1,134,918</td>
<td>34.18%</td>
</tr>
<tr>
<td>2005</td>
<td>3,562,834</td>
<td>1,291,003</td>
<td>36.24%</td>
</tr>
<tr>
<td>2006</td>
<td>4,048,235</td>
<td>1,209,415</td>
<td>29.88%</td>
</tr>
<tr>
<td>2007</td>
<td>3,824,498</td>
<td>1,286,437</td>
<td>33.64%</td>
</tr>
</tbody>
</table>
State-level Emissions from Crop Residue Burning

Average Annual PM2.5 Emissions (Gg)

- 0.0 - 0.08
- 0.081 - 0.22
- 0.221 - 0.55
- 0.551 - 0.98
- 0.981 - 3.6

Kilometers
County-level Emissions from Crop Residue Burning
Source Counties for Crop Residue Burning Emissions

- ~15.5 million people directly affected
- 5.2% of the total population of the CONUS.
- TX = 13.8%; WA = 17.5%; CA = 17.3%; FL = 17.9%; AR = 25%; ID = 46.6%.
Average contribution of emissions by crop type for the EPA source regions for years 2003-2007.
Seasonal Variability of Emissions

- CO emissions for source EPA regions
  - Average, 2003-2007

- Most burning in fall and spring
### Interannual Variability of Emissions

<table>
<thead>
<tr>
<th>Years</th>
<th>CO₂ (Tg)</th>
<th>CH₄ (Gg)</th>
<th>CO (Gg)</th>
<th>NO₂(Gg)</th>
<th>SO₂ (Gg)</th>
<th>PM₂.5 (Gg)</th>
<th>PM₁₀ (Gg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>6.5</td>
<td>9.1</td>
<td>252.1</td>
<td>12.2</td>
<td>5.2</td>
<td>22.3</td>
<td>29.0</td>
</tr>
<tr>
<td>2004</td>
<td>6.0</td>
<td>9.2</td>
<td>230.4</td>
<td>11.3</td>
<td>4.3</td>
<td>21.1</td>
<td>28.2</td>
</tr>
<tr>
<td>2005</td>
<td>6.1</td>
<td>9.4</td>
<td>234.0</td>
<td>11.1</td>
<td>4.4</td>
<td>21.4</td>
<td>29.1</td>
</tr>
<tr>
<td>2006</td>
<td>5.7</td>
<td>8.4</td>
<td>212.3</td>
<td>9.4</td>
<td>4.0</td>
<td>19.2</td>
<td>26.4</td>
</tr>
<tr>
<td>2007</td>
<td>6.2</td>
<td>9.3</td>
<td>240.2</td>
<td>11.1</td>
<td>5.1</td>
<td>21.0</td>
<td>29.2</td>
</tr>
<tr>
<td>Average</td>
<td>6.1</td>
<td>9.1</td>
<td>233.8</td>
<td>11.0</td>
<td>4.6</td>
<td>21.0</td>
<td>28.4</td>
</tr>
<tr>
<td>Average Interannual Variability (%)</td>
<td>5.1%</td>
<td>5.9%</td>
<td>7.8%</td>
<td>9.1%</td>
<td>10%</td>
<td>7.1%</td>
<td>7.1%</td>
</tr>
</tbody>
</table>

- Varied less than 10% over five years
Uncertainties: Fuel Load and Combustion Efficiency

• Average Fuel Loads obtained from three sources

– EPA AP-42

– Independent verification by in-field collaborators

• Bailed and weighed remaining residues for wheat (AR, KS, WA)

– Scientific literature for bluegrass (Johnston and Golob, 2004)

• Combustion Efficiency

– Main determinant is moisture content (most fuels burned dry; sugarcane exception)

– CE values were derived from expert knowledge from agriculture extension agents in Arkansas, Louisiana, Florida, Kansas, and Washington during field campaigns in 2004, 2005, and 2006 as well as from the scientific literature (Dennis et al., 2002; Johnston and Golob, 2004)

– CE variables ranged from 0.65 for cotton and sugarcane and 0.85 for wheat and bluegrass

• CE value used by the EPA in the Greenhouse Gas Inventory is 0.88 (EPA, 2008b)

• EPA CE value was a best guess estimate of combustion completeness of all types of biomass for international methane emissions (EPA, 1994)

Winter wheat in Arkansas; CE ~ 0.90
Uncertainties: Emission Factors

- Crop Specific Emission Factor Database
  - Eleven sources from the scientific literature and governmental reports
  - Few seasonal emission factors available; spring EFs 40% less but Fuel Loads were 3% higher
  - Uncertainty estimations?

<table>
<thead>
<tr>
<th>Crop Type</th>
<th>CO₂</th>
<th>CH₄</th>
<th>CO</th>
<th>NO₂</th>
<th>SO₂</th>
<th>PM₂.₅</th>
<th>PM₁₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bluegrass</td>
<td>1551.22</td>
<td>5.11</td>
<td>91.05</td>
<td>2.16</td>
<td>0.40</td>
<td>11.61</td>
<td>15.82</td>
</tr>
<tr>
<td>2,3,7,8,9,10</td>
<td>50.25</td>
<td>4.32</td>
<td>43.79</td>
<td>0.64</td>
<td></td>
<td>7.69</td>
<td>10.40</td>
</tr>
<tr>
<td>Rice</td>
<td>1515.69</td>
<td>2.09</td>
<td>52.63</td>
<td>3.12</td>
<td>1.38</td>
<td>5.76</td>
<td>3.31</td>
</tr>
<tr>
<td>2,5,6,7,9,10,11</td>
<td>0.94</td>
<td></td>
<td>28.07</td>
<td>1.25</td>
<td>1.72</td>
<td>4.82</td>
<td>0.22</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>1515.69</td>
<td>1.19</td>
<td>58.48</td>
<td>3.03</td>
<td>1.66</td>
<td>4.35</td>
<td>4.92</td>
</tr>
<tr>
<td>2,3,9,10,11</td>
<td>1.31</td>
<td></td>
<td>27.54</td>
<td>1.65</td>
<td>2.00</td>
<td>0.57</td>
<td>0.73</td>
</tr>
<tr>
<td>Wheat</td>
<td>1631.97</td>
<td>2.12</td>
<td>55.14</td>
<td>1.99</td>
<td>0.44</td>
<td>4.03</td>
<td>6.61</td>
</tr>
<tr>
<td>1,2,3,4,5,6,7,9,10,11</td>
<td>1.20</td>
<td></td>
<td>22.04</td>
<td>0.83</td>
<td>0.04</td>
<td>1.46</td>
<td>2.98</td>
</tr>
</tbody>
</table>

Emission factors for various crop types (g/kg); sources include: ¹Air Sciences, Inc. (2003); ²Andreae and Merlet (2001); ³Dennis et al. (2002); ⁴Dhammapala et al (2006); ⁵Hays et al. (2005); ⁶IPCC (1996); ⁷Jenkins et al. (1996); ⁸Johnston and Golob (2004); ⁹Lemieux et al. (2004); ¹⁰UK EFDB (2000); ¹¹WRAP (2005).
Comparison with U.S. Agriculture and Forestry Greenhouse Gas Inventory, 1999-2005 (USDA GCPO, 2008)

- Crop residue burning emission estimates from the EPA Greenhouse Gas Inventory (CH$_4$ emissions);
  - USDA ranks (descending order): Iowa, Illinois, Minnesota, Nebraska, Arizona, Indiana, Kansas, Arkansas, Ohio, and South Dakota.
  - This analysis (descending order): Idaho, Washington, Florida, Texas, Arkansas, Kansas, Oregon, South Dakota, North Dakota, and Missouri.
    - Arkansas, Kansas, and South Dakota in both studies.
  - USDA overestimates the contribution of crop residue burning emissions from the Midwestern states of Illinois, Iowa, Indiana, Minnesota, Nebraska, and Ohio;
    - Mainly corn and soy emissions.
    - Missing wheat, rice, and sugarcane emissions.
Transfer of results

• Linking satellite data and science to enhance fire emissions within the EPA’s National Emissions Inventory (NASA Decisions Support)
  • EPA, NASA Langley, National Institute of Aerospace, Michigan Tech, U of L
    – Deliver 2003-2012 cropland/rangeland BA and emissions to EPA for integration in NEI; Integrate trajectory calculations from CALIPSO
    – Integrate cropland and rangeland BA data with Wildfire Emissions Information System (Nancy French, MTRI)
  • Developed CONUS-specific dNBR and other existing burned area datasets
Improve Crop Type Mapping

- USDA/NASS Cropland Data Layer
  - Crop type mapping using 56 m AWiFS/30 m Landsat/10 m SPOT/250 m MODIS data
  - Spatial extent: CONUS-wide mapping for 2009, 2010
  - Current Decisions Project with SDSU, USDA/NASS, UMd, U of L
    - Integrating MODIS crop characterization capabilities with AWiFS and agricultural survey data to improve the accuracy and timeliness of national crop acreage forecasts provided by the USDA NASS Cropland Data Layer Decision Support System.
    - Result: increased accuracy of mapping winter wheat to 93% from 78%
Preliminary Results: Crop Residue Burning in Russia
Crop Residue Burning in Russia

Monthly cropland fires detected by 1km MODIS active fire, defined as IGBP classes 12 and 14, in Russia, 2001-2008.
Zoom in of MODIS (Aqua) Image on 24 April 2009: Agricultural fields burning near Moscow
Zoom in of MODIS (Aqua) Image on 26 April 2010: Agricultural fields burning in western Siberian Plain
Limitations with existing data and previous methods

• Initial research: Assign 1 km MODIS Active Fire (MOD14/MYD14) with land cover from 1 km MODIS Land Cover Dataset (MOD12) (Korontzi et al., 2006)

• Accuracy assessment of active fire detections
  – Limited coincidental high resolution data (ASTER, Landsat)

• Accuracy of land cover dataset
  – According to collaborators, Russia has not produced moderate to high resolution land cover map
  – Limited ground-level crop data (compared to USDA CDL)
Identifying Cropland Burning in Russia

• MODIS best instrument to create daily/weekly BA and/or active fire record of ag burning

• Land cover data sets must be improved
  – Ground truth data from Soil Institute

• Next step: compile and compare existing BA datasets and Russia-specific dNBR for emissions calculations
Questions?
Comparison with National Emissions Inventory

• CONUS crop residue burning emissions accounted for ~ 6% of total CO, PM$_{2.5}$, PM$_{10}$, and SO$_2$ emissions of all burning activity reported in the 2002 NEI

• Crop residue burning emissions accounted for ~ 0.04% from all SO$_2$ emissions, 1% of total PM$_{2.5}$ emissions, 0.2% of total PM$_{10}$ emissions, and 0.3% of total CO emissions

• Exceeded and/or nearly exceeded emissions from various industrial sources
  – storage and transport of petroleum and petroleum products, chemical manufacturing, petroleum and related industries, and metals processing
Comparison with Other Agricultural Burning Emission Estimates

• CONUS CO$_2$, CO, and CH$_4$ emissions accounted for 0.6% and 2.1% of total global agricultural emissions from Andreae and Merlet (2001) and Yevich and Logan (2003)
  – All agricultural burning

• CONUS crop residue burning emissions accounted for an average of 14.3% of CO and 15.9% of PM$_{2.5}$ emissions from all agricultural burning in North America (Wiedinmyer et al., 2006)

• Remote sensing-based studies
  – CONUS crop residue burning emissions accounted for an average of 26.3% of emissions from residue burning for China and India