Global PM$_{10}$ and PM$_{2.5}$ emission inventories from agricultural tilling and harvesting

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Objectives

Developing agricultural dust emission inventory:

1. Magnitude
   How much PM$_{10}$ and PM$_{2.5}$ are annually released?

2. Characteristics
   How are the spatial and temporal distributions of emissions?

3. Uncertainty
   What are the potential challenges in the inventory?
# Natural and anthropogenic sources

## Multiple Effects

1. Clouds and precipitation
2. Radiative energy balance
3. Atmospheric composition and chemistry
4. Major biogeochemical cycles
5. Ecosystem functioning
6. Socioeconomic systems and human well-being

## Major Dust Sources

- Desert dust
- Wind erosion
- Exposed riverbeds and shoreline
- Farm tilling
- Dirty road and traffic
- Crop harvesting
- Heavy construction
- Land preparation
How agricultural dust affect air quality?

Agricultural operations account for 29% of miscellaneous sources (USEPA, national inventory, 2002)

1) Direct transport
2) Indirect road dust and secondary aerosol
3) Poisonous substances, virus, bacteria could be transport with fine particles
**Workflow to estimate Ag. dust emission**

**Emission Algorithm**

\[ E = \sum_{i=1}^{M} \sum_{j=1}^{N} (EF_{ij} \times A_j \times p_i)(1 - c_i) \times k \]

EF: kg PM$_{10}$ per acre of operation activity; A: crop area; P: pass times; c: conservation operations; k: PM$_{2.5}$ coefficient factor

**Input Data**

1. Crop areas
   Wheat, corn, soybean, barley, millet, potato, rice...

2. Crop calendars
   Start and end time and duration for planting and harvesting

3. Emission factors
   Tilling, planting, harvesting

4. Others
   soil silt, monthly soil moisture, wind speed

**Workflow to estimate Ag. emission**

- **Operation specific Emission Factors (EF$_{opt}$)**
- **Crop Calendar (Number of passes)**
  \[ \sum (EF_{opt} \times \text{passes}) \]
- **Crop specific Emission Factor (EF$_{crop}$)**
- **Crop specific Acres**
  \[ EF_{crop} \times \text{Acres} \]
- **Crop types**
- **Crop specific Emissions**
- **Combined Dust Emission**
- **Meteorology Adjustment**
- **Agricultural Dust Emissions**
Crop areas and Calendars

1. Crop Area: *Spatial Production Allocation Model (SPAM)*, SPAM2000v3.02 (You et al., 2006); crop type: 20; resolution: 5 arc-minute

2. Crop Calendar: *Crop planting dates: an analysis of global patterns* (William et al., 2010); crop type: 19; resolution: 1 degree
Emission Factor (EF)

**EF sources:** EPA; CARB, EEA, CA (based on field operations); publications

*Large range of EF for different tilling operations: 0.1-14 kg PM$_{10}$ ha$^{-1}$

*EF in dry climate are 10 or 5 times than wet climate*

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### CARB: California Air Resource Board

<table>
<thead>
<tr>
<th>Activity</th>
<th>Emission Factor (lbs PM$_{10}$/acre-pass)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Preparation</td>
<td>0.3</td>
</tr>
<tr>
<td>Root cutting</td>
<td>1.2</td>
</tr>
<tr>
<td>Discing, Tilling, Chiseling</td>
<td>4.6</td>
</tr>
<tr>
<td>Ripping, Subsoiling</td>
<td>12.5</td>
</tr>
<tr>
<td>Land Planing &amp; Floating</td>
<td>0.8</td>
</tr>
<tr>
<td>Weeding</td>
<td>4.0</td>
</tr>
<tr>
<td>EPA AP-42 Tilling (old)</td>
<td>0.4</td>
</tr>
</tbody>
</table>

### EEA: Europe Environment Agency

<table>
<thead>
<tr>
<th>Crop type</th>
<th>Wet Climate</th>
<th>Dry Climate (Mediterranean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil cultivation</td>
<td>Crop harvest</td>
<td>Crop cleaning</td>
</tr>
<tr>
<td>wheat</td>
<td>0.25</td>
<td>0.49</td>
</tr>
<tr>
<td>Rye</td>
<td>0.25</td>
<td>0.37</td>
</tr>
<tr>
<td>Barley</td>
<td>0.25</td>
<td>0.41</td>
</tr>
<tr>
<td>Oat</td>
<td>0.25</td>
<td>0.62</td>
</tr>
<tr>
<td>Other</td>
<td>0.25</td>
<td>NA</td>
</tr>
<tr>
<td>Grassland</td>
<td>0.25</td>
<td>0.25</td>
</tr>
</tbody>
</table>

### Basic emission factors (kg PM$_{10}$ ha$^{-1}$ per pass) we used here

<table>
<thead>
<tr>
<th>Crop type</th>
<th>Tillage (kg PM$_{10}$ ha$^{-1}$)</th>
<th>Planting/Cutting (kg PM$_{10}$ ha$^{-1}$)</th>
<th>Harvest$^*$ (kg PM$_{10}$ ha$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>wheat</td>
<td>5.17</td>
<td>1.35</td>
<td>6.57/2.36</td>
</tr>
<tr>
<td>Winter-wheat</td>
<td>5.17</td>
<td>1.35</td>
<td>6.5/2.34</td>
</tr>
<tr>
<td>maize</td>
<td>5.17</td>
<td>1.35</td>
<td>1.88/0.68</td>
</tr>
<tr>
<td>Maize2</td>
<td>5.17</td>
<td>1.35</td>
<td>1.88/0.68</td>
</tr>
<tr>
<td>soybean</td>
<td>5.17</td>
<td>1.35</td>
<td>1.88/0.68</td>
</tr>
<tr>
<td>Rice</td>
<td>1.35</td>
<td>0</td>
<td>1.88/0.68</td>
</tr>
<tr>
<td>Rice2</td>
<td>1.35</td>
<td>0</td>
<td>1.88/0.68</td>
</tr>
<tr>
<td>sorghum</td>
<td>5.17</td>
<td>1.35</td>
<td>6.5/2.34</td>
</tr>
<tr>
<td>Winter-sorghum</td>
<td>5.17</td>
<td>1.35</td>
<td>6.5/2.34</td>
</tr>
<tr>
<td>cotton</td>
<td>5.17</td>
<td>1.35</td>
<td>3.77/1.36</td>
</tr>
<tr>
<td>barley</td>
<td>5.17</td>
<td>1.35</td>
<td>6.5/2.34</td>
</tr>
<tr>
<td>Millet</td>
<td>5.17</td>
<td>1.35</td>
<td>1.88/0.68</td>
</tr>
<tr>
<td>Potato</td>
<td>5.17</td>
<td>0.34</td>
<td>1.88/0.68</td>
</tr>
<tr>
<td>Winter-barley</td>
<td>5.17</td>
<td>1.35</td>
<td>6.5/2.34</td>
</tr>
<tr>
<td>Groundnut</td>
<td>5.17</td>
<td>0.34</td>
<td>1.88/0.68</td>
</tr>
<tr>
<td>Pulses</td>
<td>5.17</td>
<td>1.35</td>
<td>1.88/0.68</td>
</tr>
<tr>
<td>Sweet-potato</td>
<td>5.17</td>
<td>0.34</td>
<td>1.88/0.68</td>
</tr>
</tbody>
</table>
EF adjustment by soil and climate factors

- Controlling factors: operation types, soil property and climate conditions
- EFs increase with increasing soil silt, wind speed and decreasing soil moisture

Adjustment method: four steps

1. Basic EF: e.g., 5.17 kg ha⁻² for joint tilling operation in dry climate condition
2. soil silt content: EF_silt <- EF × soil silt⁽⁰.⁶⁾
3. soil moisture: M <= 15%, CF=1.0; M > 15% & M <= 20 % CF=0.6; M > 25% & M <= 30%, CF=0.1; M > 30%, CF=0.1
4. wind speed: WS >= 6 m s⁻¹, CF=1.5; WS >= 4 & WS < 6, CF=1; WS >= 2 & WS < 4, CF=0.6; WS <= 2, CF=0.3
Spatial distribution of agricultural PM$_{10}$ emissions

Intense regions: Central US, Northern China, Pakistan, India, Turkey, Southeast Africa
Spatial distribution of agricultural PM$_{2.5}$ emissions

Conversion coefficients of PM$_{2.5}$ and PM$_{10}$:

*North and South America, 0.125 (CARB); others, 0.06 (EEA)*
Ten regions are divided mainly based on Paul Ginoux et al., 2012
Regional Comparison
North America, East Asia, North Africa and South Asia

Left or top: satellite
Red: anthropogenic source
Yellow: natural sources
Right or down are our data
Regional Comparison
West Asia, South America and Australia

1. Most agricultural PM sources are similar with natural sources by AOD data.
2. Emission sources from AOD data are always larger than emission area because AOD normally represents transported aerosol plumes.
Major emission months

1. North America: 5, 9, 10
2. Europe: 10
3. East Asia: 5, 6, 9
4. North Africa: 6, 7, 10, 12
5. South Asia: 6, 11
6. Australia: 5, 12
7. West Asia: 6, 10, 11
8. South America: 11, 12
9. South Africa: 10
10. North Asia: 5, 9
### Annual PM$_{10}$ Emission in Different Regions

- **Order:** North America > North Africa > Europe > East Asia > South Asia
- **PM$_{10}$ emission in America is approximately 1/20 lower than NEI (2005)**

<table>
<thead>
<tr>
<th>Region</th>
<th>Longitude Range</th>
<th>Latitude Range</th>
<th>Tillage Emission (kiloton)</th>
<th>Planting/Cutting Emission (kiloton)</th>
<th>Harvest Emission (kiloton)</th>
<th>Total Emission (kiloton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td>125°W-70°W</td>
<td>20°N-60°N</td>
<td>43.0</td>
<td>10.9</td>
<td>91.8</td>
<td>145.8</td>
</tr>
<tr>
<td>South America</td>
<td>85°W-50°W</td>
<td>55°S-0°S</td>
<td>13.9</td>
<td>3.5</td>
<td>22.9</td>
<td>40.3</td>
</tr>
<tr>
<td>Europe</td>
<td>9°W-60°E</td>
<td>40°N-71°N</td>
<td>41.5</td>
<td>10.8</td>
<td>31.9</td>
<td>84.2</td>
</tr>
<tr>
<td>North Africa</td>
<td>20°W-35°E</td>
<td>5°N-40°N</td>
<td>40.8</td>
<td>9.9</td>
<td>47.0</td>
<td>97.7</td>
</tr>
<tr>
<td>South Africa</td>
<td>5°E-50°E</td>
<td>35°S-5°N</td>
<td>13.1</td>
<td>3.2</td>
<td>9.4</td>
<td>25.7</td>
</tr>
<tr>
<td>West Asia</td>
<td>35°E-60°E</td>
<td>5°N-40°N</td>
<td>12.0</td>
<td>3.1</td>
<td>20.5</td>
<td>35.6</td>
</tr>
<tr>
<td>North Asia</td>
<td>60°E-140°E</td>
<td>50°N-71°N</td>
<td>8.0</td>
<td>2.1</td>
<td>9.3</td>
<td>19.4</td>
</tr>
<tr>
<td>South Asia</td>
<td>60°E-100°E</td>
<td>5°N-30°N</td>
<td>28.1</td>
<td>5.5</td>
<td>23.9</td>
<td>57.6</td>
</tr>
<tr>
<td>East Asia</td>
<td>60°E-140°E</td>
<td>30°N-50°N</td>
<td>31.9</td>
<td>7.6</td>
<td>24.8</td>
<td>64.3</td>
</tr>
<tr>
<td>Australia</td>
<td>110°E-155°E</td>
<td>45°S-10°S</td>
<td>8.3</td>
<td>2.1</td>
<td>19.5</td>
<td>29.9</td>
</tr>
<tr>
<td>Total</td>
<td>180°W-180°E</td>
<td>90°S-90°N</td>
<td>266.5</td>
<td>63.6</td>
<td>332.9</td>
<td>663.0</td>
</tr>
</tbody>
</table>
Summary

1. The inventory could reflect spatial distribution and temporal variation of agricultural PM emissions in major regions

2. Large uncertainty of emission magnitude

   - Decrease the passes for tilling operations because the use of combined tillage machine are increasing
   - PM from grassland productions are not involved, which may decrease PM emission in many grassland regions
   - Local EF values are rare around the world, especially in Asia and Africa
   - The classes of adjustment by soil and climate factor may give bias for inventory

Future works

- Verification of agricultural emission inventory in major regions
- Apply the emission inventory to CMAQ and test in CONUS and northeastern China
Thanks for your time!