HyCAMP

National Emission Inventory of Black Carbon; Uncertainty Analyses

Dr. Mukesh Sharma
Umed Paliwal
Department of Civil Engineering
Indian Institute of Technology Kanpur

Anil Agarwal Dialogue 2015
Importance

- Deposition of light absorbing pollutants (e.g., Black Carbon) enhance the rate of melting of glaciers.
- Himalayan glaciers are central to India’s water needs, they supply water to large river systems that support millions of people inhabiting the surrounding areas.

Himalayan Snow covered with Black Carbon
Health Importance

The systematic review of the available time-series studies, as well as information from panel studies, provides sufficient evidence of an association of short-term (daily) variations in BC concentrations with short-term changes in health (all-cause and cardiovascular mortality, and cardiopulmonary hospital admissions). Cohort studies provide sufficient evidence of associations of all-cause and cardiopulmonary mortality with long-term average BC exposure.
Why Emission Inventory

Analysis, Impact, Exposure, Strategy, Control need Emission Inventory: Challenges?

Resolution:

Climate Impact: Coarse (40 km x 40 km)
Health Impact: Fine (2km x 2km)

Challenges: Many
Uncertainty in Activity data and Emission Factors
EMISSION INVENTORY, WHY GIS?

Often our Inventories are ‘Tables’……

<table>
<thead>
<tr>
<th>PM10</th>
<th>CO</th>
<th>SO2</th>
<th>NOx</th>
</tr>
</thead>
<tbody>
<tr>
<td>961.41</td>
<td>5047.42</td>
<td>60.09</td>
<td>360.53</td>
</tr>
<tr>
<td>1406.75</td>
<td>7385.45</td>
<td>87.92</td>
<td>527.53</td>
</tr>
<tr>
<td>1447.48</td>
<td>7599.27</td>
<td>90.47</td>
<td>542.80</td>
</tr>
<tr>
<td>1005.39</td>
<td>5278.27</td>
<td>62.84</td>
<td>377.02</td>
</tr>
<tr>
<td>1894.00</td>
<td>9943.53</td>
<td>118.38</td>
<td>710.25</td>
</tr>
<tr>
<td>1725.42</td>
<td>9058.45</td>
<td>107.84</td>
<td>647.03</td>
</tr>
</tbody>
</table>

- **Advantages** -
  - More understandable and accessible
  - Increase integration and consistency
  - Provide various analytical tool for database
  - Visualization, Mapping and Modeling
Activity_{projected} = f (Activity_{baseyear}, Growth rate)

PEC_{ij} = f (Activity_{ij}, Emission Factor_{ij})

Total Emission_{j} = \sum_{i=1}^{i=Source} PEC_{ij}

i=Source
j=Location
PEC_{ij} = Projected Emissions of BC

Display on gridded Base map of India

(40 x 40 km²)
POINT SOURCES

Thermal Plants

Steel Plants
Cement plants
AREA SOURCES

District wise Emission Density (ED) = Emission / District Area (km²)

Grid wise Emission = \( \sum \) (Intersected district area \times ED)
## SOURCES

<table>
<thead>
<tr>
<th>Sector</th>
<th>Sub Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic Fuel</td>
<td>Firewood</td>
</tr>
<tr>
<td></td>
<td>Agriculture Residue</td>
</tr>
<tr>
<td></td>
<td>Coal</td>
</tr>
<tr>
<td></td>
<td>LPG</td>
</tr>
<tr>
<td></td>
<td>Kerosene</td>
</tr>
<tr>
<td></td>
<td>Dung Cake</td>
</tr>
<tr>
<td>Open Burning</td>
<td>Waste Burning</td>
</tr>
<tr>
<td></td>
<td>Crop Residue Burning</td>
</tr>
<tr>
<td></td>
<td>Forest Fire</td>
</tr>
<tr>
<td>Industry</td>
<td>Brick</td>
</tr>
<tr>
<td></td>
<td>Cement</td>
</tr>
<tr>
<td></td>
<td>Steel</td>
</tr>
<tr>
<td></td>
<td>Sugar</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sector</th>
<th>Sub Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport</td>
<td>Two Wheeler</td>
</tr>
<tr>
<td></td>
<td>Trucks</td>
</tr>
<tr>
<td></td>
<td>LMV Passenger</td>
</tr>
<tr>
<td></td>
<td>LCV</td>
</tr>
<tr>
<td></td>
<td>Car</td>
</tr>
<tr>
<td></td>
<td>Taxi</td>
</tr>
<tr>
<td></td>
<td>Bus</td>
</tr>
<tr>
<td></td>
<td>Tractors &amp; Trailers</td>
</tr>
<tr>
<td></td>
<td>Railways</td>
</tr>
<tr>
<td>Power Plants</td>
<td>Diesel &amp; Coal</td>
</tr>
</tbody>
</table>

**Comprehensive source selection**
EMISSION INVENTORY, CHALLENGES

- Large variation in Activity data and Emission factors
- No point estimate is better or worse than other

Previous studies

This study
METHODOLOGY - MONTE CARLO SIMULATION

Source, n

Activity Data Through Different sources
Distribution Fitting
Random Numbers

Emission Factor from Different sources
Distribution Fitting
Random Numbers

Emissions

Gridded Emission

Source n+1

Emission Distribution and Uncertainty
## EMISSION FACTORS

<table>
<thead>
<tr>
<th>Source</th>
<th>EF (g/kg)</th>
<th>Source</th>
<th>EF(g/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brick</td>
<td>0.16±0.09</td>
<td>Brick</td>
<td>0.16±0.09</td>
</tr>
<tr>
<td>Cement</td>
<td>0.45±0.51</td>
<td>Cement</td>
<td>0.45±0.51</td>
</tr>
<tr>
<td>Crop Burning</td>
<td>0.69±0.19</td>
<td>Crop Burning</td>
<td>0.69±0.19</td>
</tr>
<tr>
<td>Forest Fire</td>
<td>0.76±0.21</td>
<td>Forest Fire</td>
<td>0.76±0.21</td>
</tr>
<tr>
<td>Garbage Burning</td>
<td>0.51±0.15</td>
<td>Garbage Burning</td>
<td>0.51±0.15</td>
</tr>
<tr>
<td>Railway Coal</td>
<td>1.67±1.25</td>
<td>Railway Coal</td>
<td>1.67±1.25</td>
</tr>
<tr>
<td>Railway Diesel</td>
<td>0.78±0.59</td>
<td>Railway Diesel</td>
<td>0.78±0.59</td>
</tr>
<tr>
<td>Steel</td>
<td>0.45±0.51</td>
<td>Steel</td>
<td>0.45±0.51</td>
</tr>
<tr>
<td>Sugar</td>
<td>0.95±0.27</td>
<td>Sugar</td>
<td>0.95±0.27</td>
</tr>
<tr>
<td>Power Coal</td>
<td>0.03±0.03</td>
<td>Power Coal</td>
<td>0.03±0.03</td>
</tr>
<tr>
<td>Power Diesel</td>
<td>0.15±0.08</td>
<td>Power Diesel</td>
<td>0.15±0.08</td>
</tr>
<tr>
<td>Bus</td>
<td>0.70±0.51</td>
<td>Bus</td>
<td>0.70±0.51</td>
</tr>
<tr>
<td>Two wheeler</td>
<td>0.02±0.01</td>
<td>Two wheeler</td>
<td>0.02±0.01</td>
</tr>
<tr>
<td>Car</td>
<td>0.09±0.06</td>
<td>Car</td>
<td>0.09±0.06</td>
</tr>
<tr>
<td>LCV</td>
<td>0.34±0.44</td>
<td>LCV</td>
<td>0.34±0.44</td>
</tr>
<tr>
<td>LMV Passenger</td>
<td>0.15±0.01</td>
<td>LMV Passenger</td>
<td>0.15±0.01</td>
</tr>
<tr>
<td>Taxi</td>
<td>0.05±0.02</td>
<td>Taxi</td>
<td>0.05±0.02</td>
</tr>
<tr>
<td>Tractor &amp; Trailer</td>
<td>0.63±0.67</td>
<td>Tractor &amp; Trailer</td>
<td>0.63±0.67</td>
</tr>
<tr>
<td>Truck</td>
<td>0.52±0.43</td>
<td>Truck</td>
<td>0.52±0.43</td>
</tr>
</tbody>
</table>
EMISSIONS FROM DOMESTIC FIREWOOD

Total Fuelwood Consumption from 3 sources

Random Numbers from fitted distribution

Firewood EF 14 sources

Random Numbers from fitted distribution
DOMESTIC COMBUSTION

BC Emission 321.75 KTon/yr

- Dung Cake: 15.05%
- Crop Residue: 23.00%
- LPG: 0.14%
- Kerosene: 0.32%
- Coal: 2.53%
- Firewood: 58.96%
# DOMESTIC COMBUSTION

<table>
<thead>
<tr>
<th>Source</th>
<th>Distribution</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firewood</td>
<td>Lognormal 3P</td>
<td>$\sigma = 0.15857 \quad \mu = 27.043 \quad \gamma = -3.725\times10^{11}$</td>
</tr>
<tr>
<td>Dung Cake</td>
<td>General Extreme Value</td>
<td>$K = 0.10209 \quad \sigma = 2.609\times10^{10} \quad \mu = 3.046\times10^{10}$</td>
</tr>
<tr>
<td>Coal</td>
<td>Gen. Gamma</td>
<td>$K = 0.37 \quad \alpha = 4.37 \quad \beta = 9.911\times10^{7} \quad \gamma = 1.28\times10^{8}$</td>
</tr>
</tbody>
</table>
OPEN BURNING

BC Emissions 100.6 Kton/yr
INDUSTRIAL EMISSIONS

BC Emissions 191.7 Kton/yr
TRANSPORTATION

BC Emission 209.12 KTon/yr
TRUCK EMISSIONS

Emission from Trucks = \( \Sigma (N \times AKT \times EF) \)

N – Number of vehicles on road determined using survival function from 1971-2011
AKT – Annual km Travelled
EF – Emission factor (g/km)

The standard deviation in emissions from truck is high because of highly variable emission factors and annual distance travelled by a truck

<table>
<thead>
<tr>
<th>Annual km. Travelled</th>
<th>EF(g/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>56350</td>
<td>1.24</td>
</tr>
<tr>
<td>30000</td>
<td>0.61</td>
</tr>
<tr>
<td>40000</td>
<td>0.26</td>
</tr>
<tr>
<td>57500</td>
<td>0.18</td>
</tr>
<tr>
<td>47000</td>
<td>0.304</td>
</tr>
</tbody>
</table>
## SOURCE-WISE BC EMISSIONS (2011)

<table>
<thead>
<tr>
<th>Source</th>
<th>Mean BC Emission (Kton/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bricks</td>
<td>$71.46 \pm 44.29$</td>
</tr>
<tr>
<td>Cement Industry</td>
<td>$14 \pm 17.60$</td>
</tr>
<tr>
<td>Crop Residue</td>
<td>$63.84 \pm 16.92$</td>
</tr>
<tr>
<td>Domestic Fuel</td>
<td>$321.75 \pm 104.49$</td>
</tr>
<tr>
<td>Garbage Burning</td>
<td>$1.66 \pm 0.64$</td>
</tr>
<tr>
<td>Sugar Industry</td>
<td>$73.92 \pm 26.12$</td>
</tr>
<tr>
<td>Transport</td>
<td>$209.12 \pm 535.73$</td>
</tr>
<tr>
<td>Forest Fire</td>
<td>$35.10 \pm 21.59$</td>
</tr>
<tr>
<td>Power Plants</td>
<td>$12.94 \pm 20.04$</td>
</tr>
<tr>
<td>Steel Industry</td>
<td>$19.38 \pm 31.74$</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$823.17 \pm 555.44$</td>
</tr>
</tbody>
</table>
ANNUAL BC EMISSIONS IN INDIA - 2011

Total BC Emission 823.17 KTon/yr
SOURCE WISE EMISSION AND STANDARD DEVIATION

Emission Kton/yr

Source

- Brick
- Cement
- Crop Residue Burning
- Forest Fire
- Garbage Burning
- Railways/Diesel
- Railways Coal
- Steel
- Sugar
- Power Plant Coal
- Power Plant Diesel
- Two Wheeler
- Bus
- Car
- LCV
- LMV/Passenger
- Taxi
- Tractor & Trailer
- Truck
- Domestic Crop Residue
- Domestic Coal
- Domestic Firewood
- LPG
- Domestic Kerosene
- Dung Cake

Mean Emission
Standard Deviation
COMPARISON WITH PREVIOUS STUDIES

BC Emissions (KTon/yr)

- Streets et al. 2003 (Base year 2000)
- Venkatraman et al. 2002 (Base year 1997)
- SAFAR 2011
- RETRO 2010
- This study (Base year 2011)
Total BC Emission = 7.12 KTon/yr
MUMBAI

Total BC Emission = 2.96 KTon/yr

Transport 83%

Open Burning 3%
Industry 5%
Domestic 9%

Transport Emissions

Truck 31%
LCV 27%
Bus 10%
Car 10%
Tractor & Trailer 4%
Taxi 1%
Railways Two Wheeler 0%
CAMx simulates the dispersion, chemical reactions, and removal of the pollutants in lower troposphere by solving the pollutant continuity equation on a system of nested three dimensional grids

\[
\frac{\partial C}{\partial t} = -\nabla H \cdot VHC + \left[ \frac{\partial (C \eta)}{\partial z} - C \frac{\partial}{\partial z} \left( \frac{\partial h}{\partial t} \right) \right] + \nabla \cdot \rho K \nabla \left( \frac{C}{\rho} \right) + \frac{\partial C}{\partial t} \text{Emiss} + \frac{\partial C}{\partial t} \text{Chem} + \frac{\partial C}{\partial t} \text{Remov}
\]

**CAMx (Comprehensive Air Quality Model)—Chemical Transport Model**

\[ C(x,t) = f(\text{Emission}_{x,t}, \text{Meteorology}_{x,t}, \text{Chemistry}) \]
The WRF model takes input of meteorological parameters for a given geographical domain and can predict the values of these parameters at finer space and time resolution.
WRF Validation - Qualitative

Lehar Cyclone 2013

- 26.11.2013 0900 HRS
- 26.11.2013 2100 HRS
- 27.11.2013 0430 HRS

Model Output

Kalpana Satellite Images
WRF Validation - Quantitative

IIT Kanpur

Domain

Grid Size –
40 km
13.33 km

Results

Correlation = 0.94

IMD Station, Joshimath, Uttrakhand

Grid Size –
27 km
9 km
3 km

Max. Correlation = 0.92
2008 STUDY

CONCENTRATIONS AT RECEPTOR SITES DUE TO EMISSIONS FROM INDIA

<table>
<thead>
<tr>
<th>Receptor Location</th>
<th>Summer</th>
<th>Monsoon</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gangotri Glacier</td>
<td>2.17±0.35</td>
<td>0.74±0.57</td>
<td>3.06±1.07</td>
</tr>
<tr>
<td>East Rongbuk Glacier</td>
<td>2.58±1.08</td>
<td>0.68±0.45</td>
<td>3.23±0.74</td>
</tr>
</tbody>
</table>

Maximum concentration values are during the summer and winter months, with very little concentration during the monsoon season.
Here, we have segregated sugarcane industry because emissions from bagasse Burning were considerably high. As could be observed, transport sector doesn’t feature among the top emitters in any of the Emissions Regions.
Control Strategies… continued

- Order of preference for BC control over the Himalayas

<table>
<thead>
<tr>
<th>Emission Region</th>
<th>1st preference</th>
<th>2nd preference</th>
</tr>
</thead>
<tbody>
<tr>
<td>ER1</td>
<td>Open Burning</td>
<td>Industry</td>
</tr>
<tr>
<td>ER2</td>
<td>Sugarcane Industry</td>
<td>Open Burning + Household</td>
</tr>
<tr>
<td>ER3</td>
<td>Household</td>
<td>Industry</td>
</tr>
<tr>
<td>ER4</td>
<td>Household</td>
<td>Open Burning</td>
</tr>
</tbody>
</table>

Based on a control in household sector, we consider two change/demand scenarios (based on Antonette and Murthy, 2005). We assume that LPG replaces dung-cake and wood consumption in domestic sector.
Demand Scenario 1- Business as usual (current growth & usage rates are used) (The study used 2005-06 as base year)

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of households using LPG (millions)</th>
<th>Proportion of total households using LPG (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rural</td>
<td>Urban</td>
</tr>
<tr>
<td>2005-06</td>
<td>10.91</td>
<td>44.87</td>
</tr>
<tr>
<td>2010-11</td>
<td>15.17</td>
<td>63.38</td>
</tr>
<tr>
<td>2015-16</td>
<td>21.10</td>
<td>72.59</td>
</tr>
</tbody>
</table>

Under this scenario, a nominal increase in households using LPG will be observed. The observed impacts will not be so prominent.
Control Strategies… continued

**Demand Scenario 2:** Here we consider the case of promoting the use of LPG in rural India (growth of rural users is doubled but current growth is considered for the urban sector.)

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of households using LPG (millions)</th>
<th>Proportion of total households using LPG (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rural</td>
<td>Urban</td>
</tr>
<tr>
<td>2010-11</td>
<td>20.67</td>
<td>63.38</td>
</tr>
<tr>
<td>2015-16</td>
<td>39.17</td>
<td>72.59</td>
</tr>
</tbody>
</table>

Under this scenario, a significant increase in rural LPG users will be observed. If this increase is taken as a mean to offset emissions from dung-cake and wood burning, we can observe large EC emission reductions from ER2, ER3 and ER4.
Thank You