WRF-CAMx Model Study for Transport of Black Carbon to the Himalayas: Regional Control Strategies

Mukesh Sharma, PhD

Professor

Department of Civil Engineering

INDIAN INSTITUTE OF TECHNOLOGY KANPUR

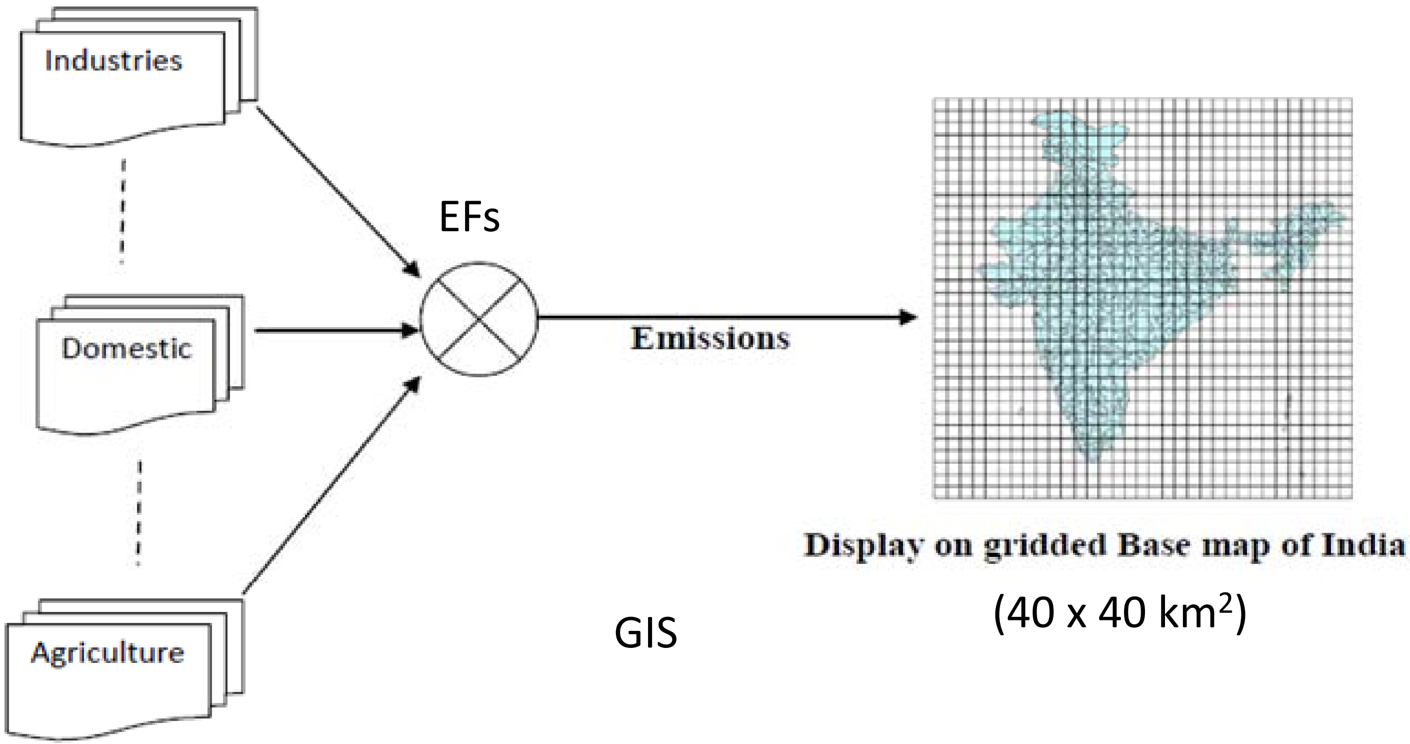
Introduction

- **BC: Impacts**
  - Global warming (40% due to BC emissions)
    - Radiative forcing: BC (+0.3W/m^2)
  - Receding Glaciers (high radiation absorbing power)
    - 4% decrease in snow cover in the Himalayas during 1997 to 2003 (Menon, 2009).
    - ISRO study: 75% of Himalayan Glaciers on retreat, average shrinkage 3.75 km in 15yr

(Source: Global Warming Center, AccuWeather.com)

A reduction in the BC emissions can lead to an immediate near term impact on reducing atmospheric warming

Mapping and Grid Extraction



$$Activity_{projected} = f\,(Activity_{baseyear}\,,\ Growth\ rate)$$

Base Year – 2001
Projected Year – 2008

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

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

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

Data Collection

Major Sectors	Sub Sectors
Domestic Combustion	Liquid Petroleum Gas (LPG)
	Kerosene
	Coal Combustion
	Fuel Wood
	Dung Cake
Open Burning	Crop Residue Burning
	Garbage Burning
Transportation	Petrol operated vehicles
	Diesel operated vehicles
Industrial	Brick Kilns
	Sugar Industry (Bagasse Burning)
	Cement Plants
	Steel Industry
	Power plants

Emission Factors

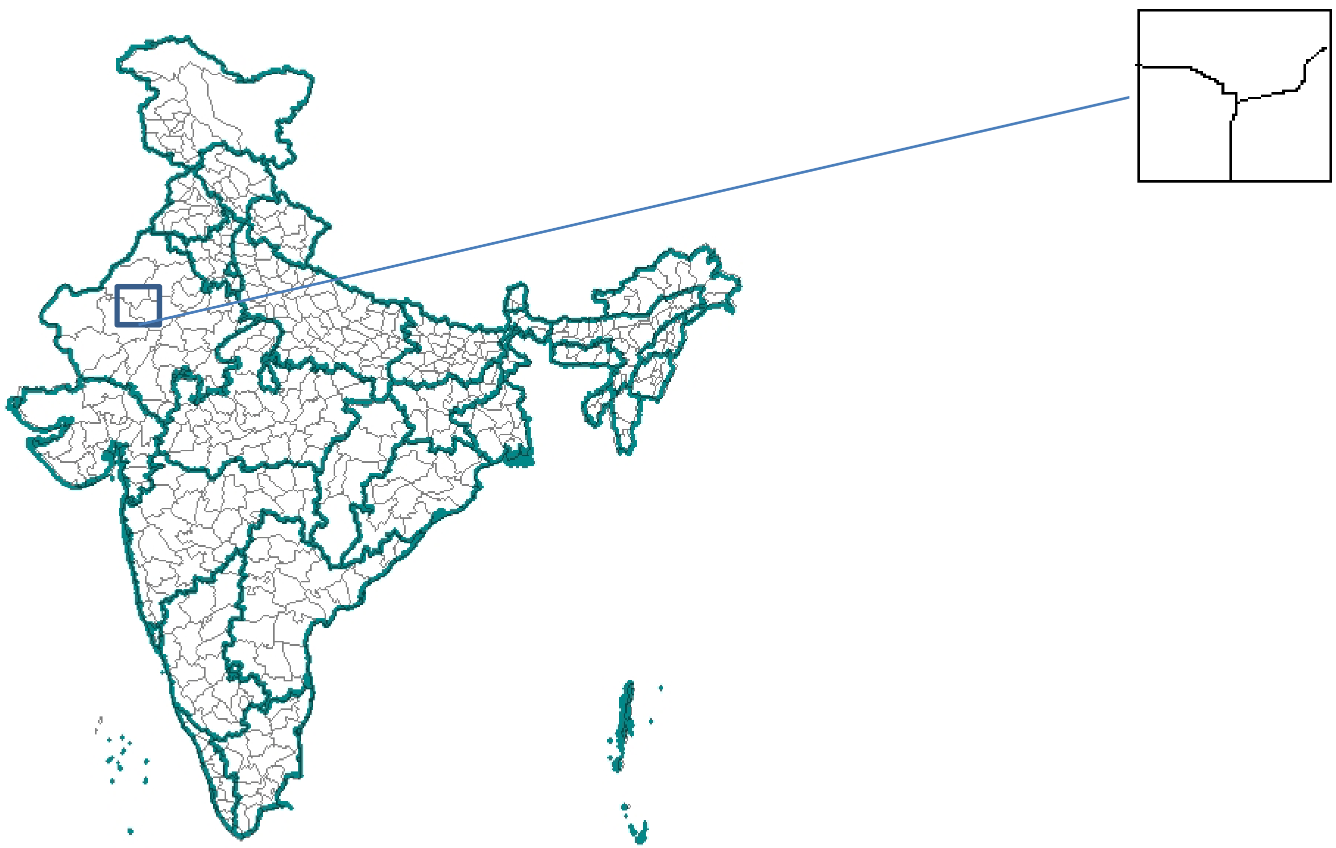
Source	BC (g/kg)
LPG	0.02
Coal	1.2
Kerosene	0.2
Fuel Wood	1.6
Crop Residue	0.64
Bagasse Burning	2.0
Industrial Coal	0.08
Vehicle (Gasoline)	0.03-1.00
Vehicle (Diesel)	1.71-5.56
Vehicles (CNG)	0.72 (derived)
Dung Cake	1.2

Sources: (a) Gadi R. and Mitra A. P., 2006(b) Venkatraman C., 2000

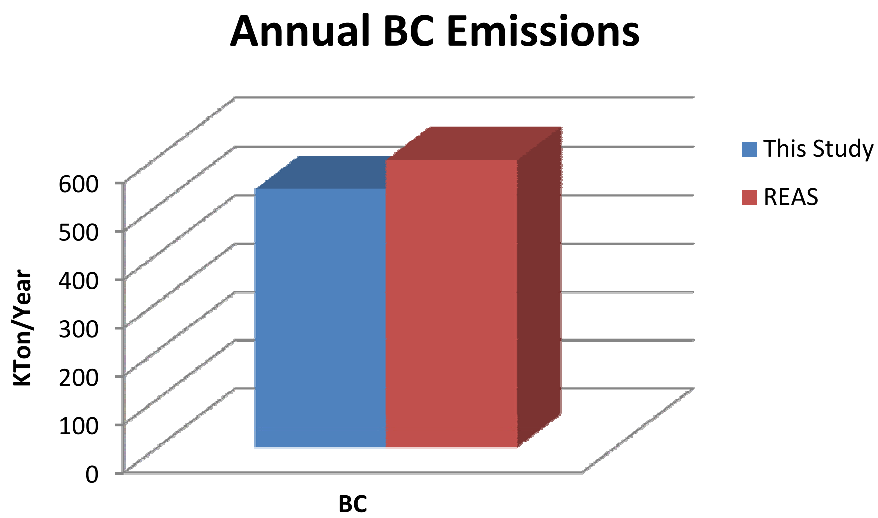
Area Sources

District wise Emission Density (ED) = Emission / District Area(km^2)

Grid wise Emission = ∑ (Intersected district area X ED)



BC Emissions (2008)



Prepared Emission Inventory v/s REAS inventory:

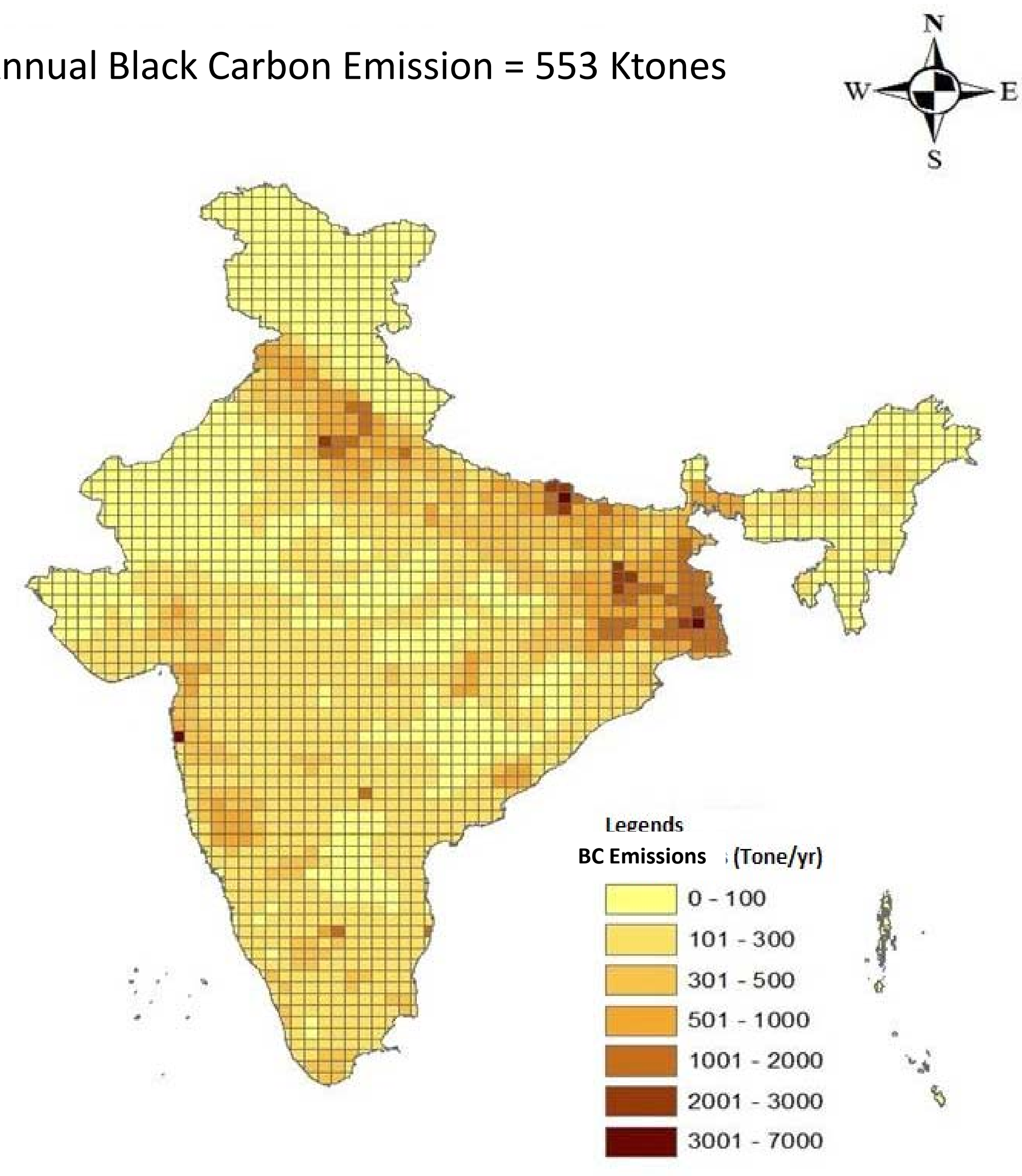
- High Resolution: 40km for this EI, 55km for REAS.
- Spatial and Temporal variability (different emission sources).
- More realistic and accurate approach: Bottom-up

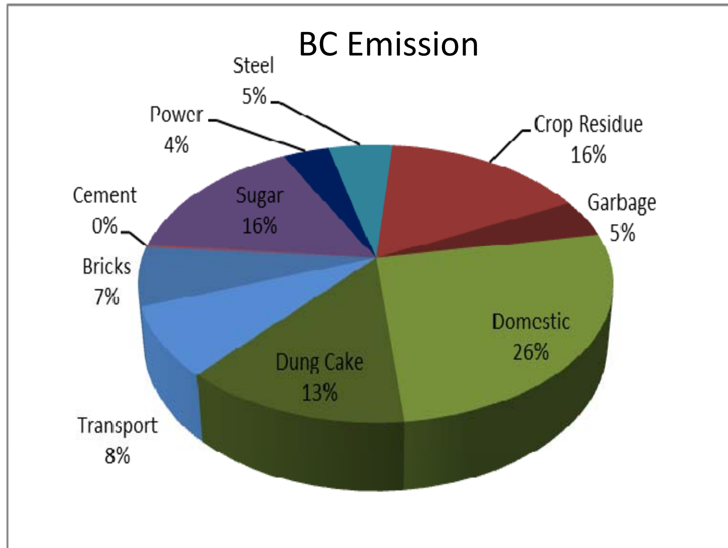
Source-wise BC Emissions (2008)

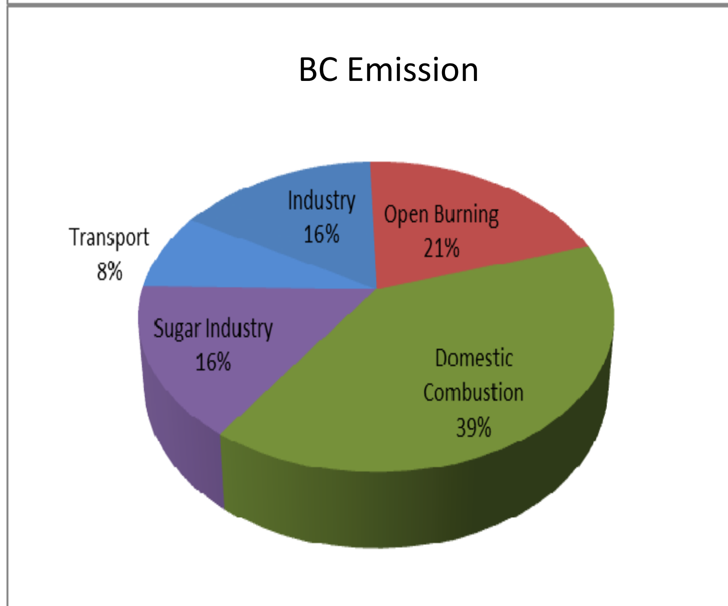
Source	BC emission(Kton/yr)
Bricks	36.59
Cement Industry	1.47
Crop Residue	87.00
Domestic	140.41
Garbage Burning	23.69
Sugar Industry	84.15
Vehicles	42.65
Dung Cake	69.65
Power Plants	20.06
Steel Industry	27.88
Total	534
REAS Inventory	596

Annual BC Emissions in India - 2008

Annual Black Carbon Emission = 553 Ktones

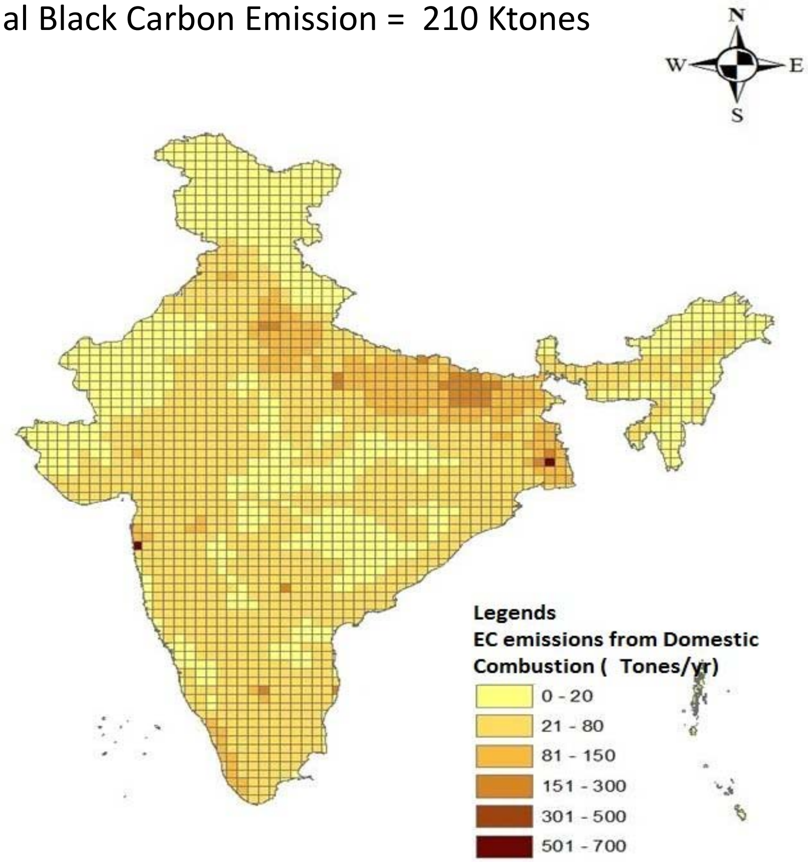




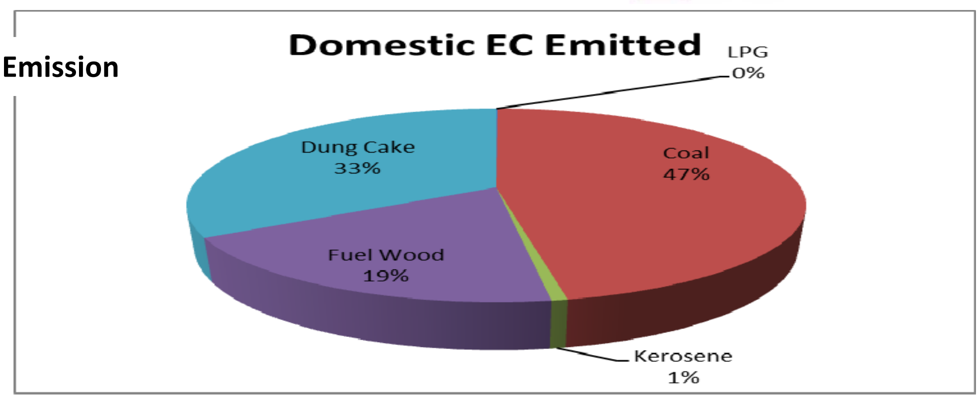


Domestic Combustion

Annual Black Carbon Emission = 210 Ktones

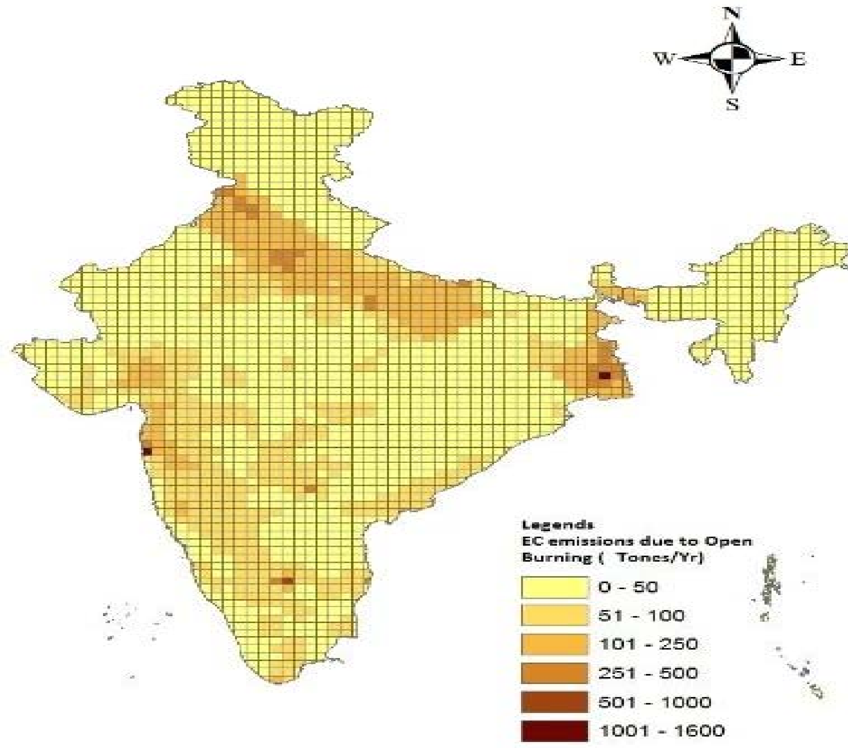


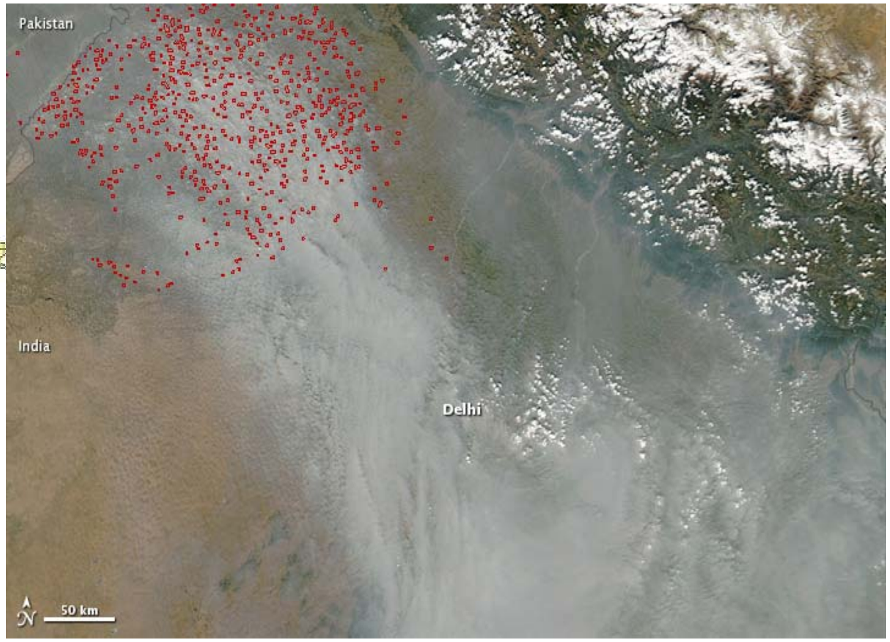
BC Emission



Open Burning

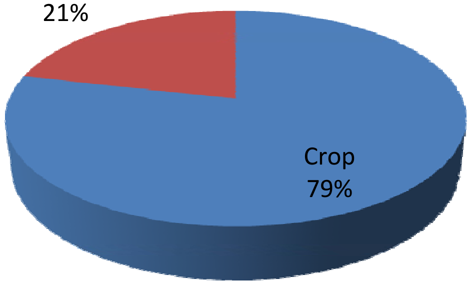
Annual Black Carbon Emission = 111 Ktones





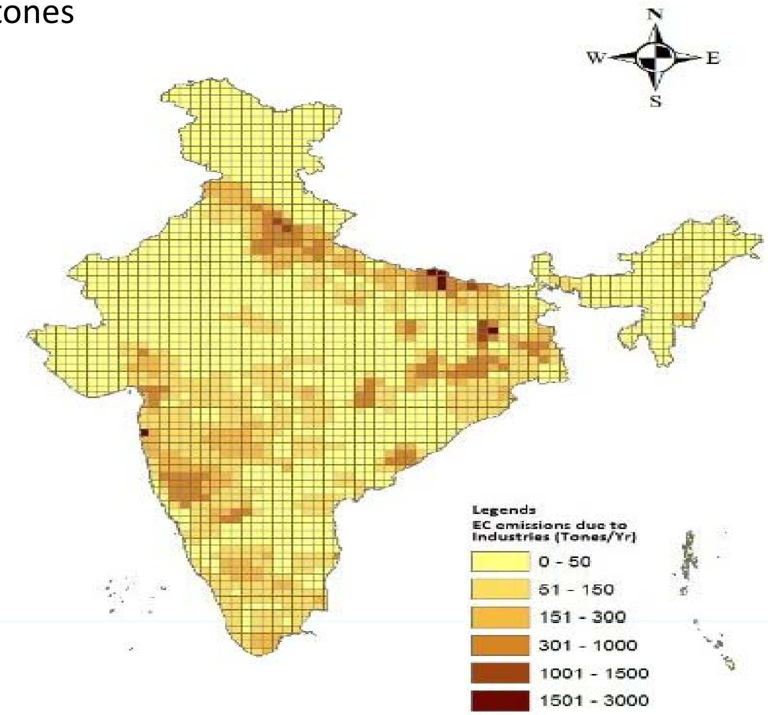
Modis – NASA Image Nov 5, 2012

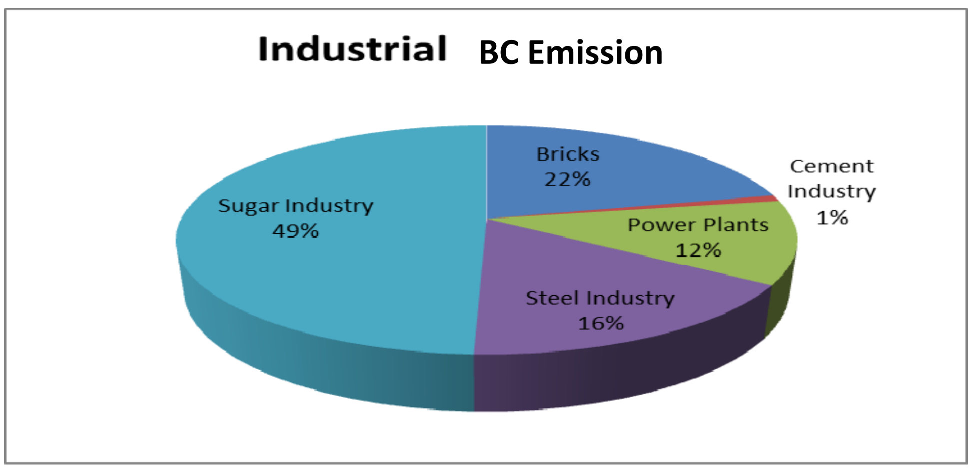
Open Burning BC



Industrial Emissions

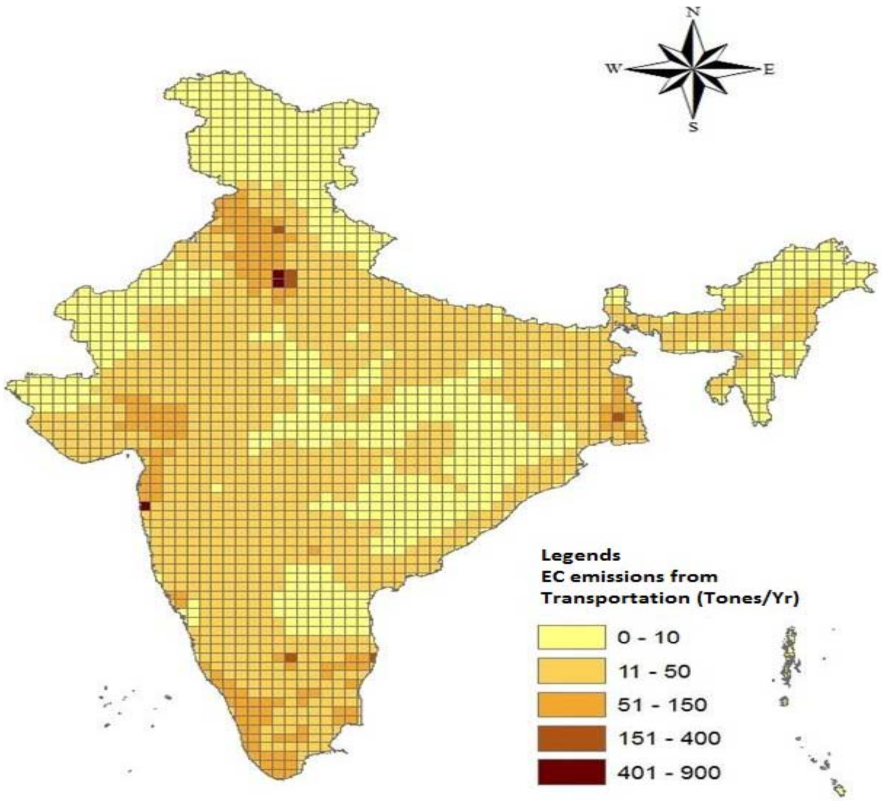
Annual Black Carbon Emission = 86 Ktones

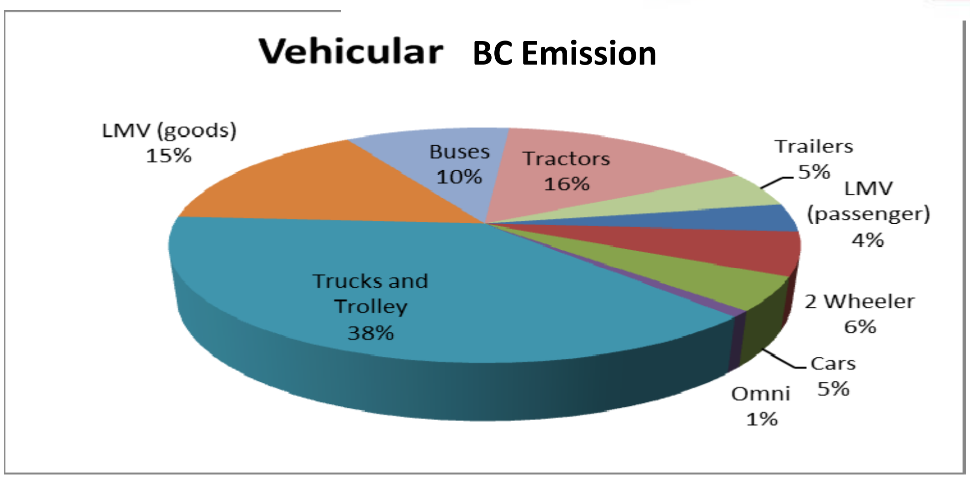




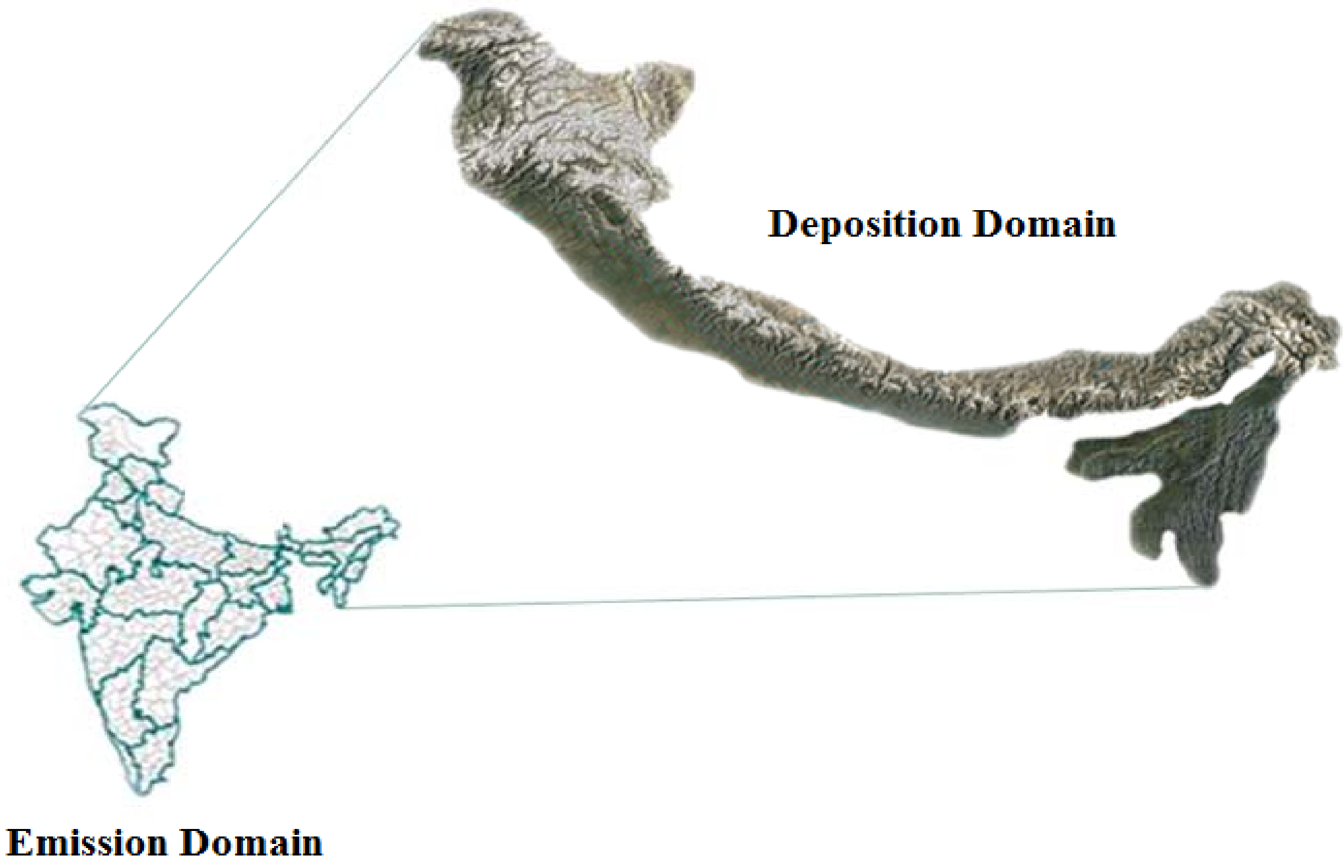
Transportation

Annual Black Carbon Emission = 43 Ktones

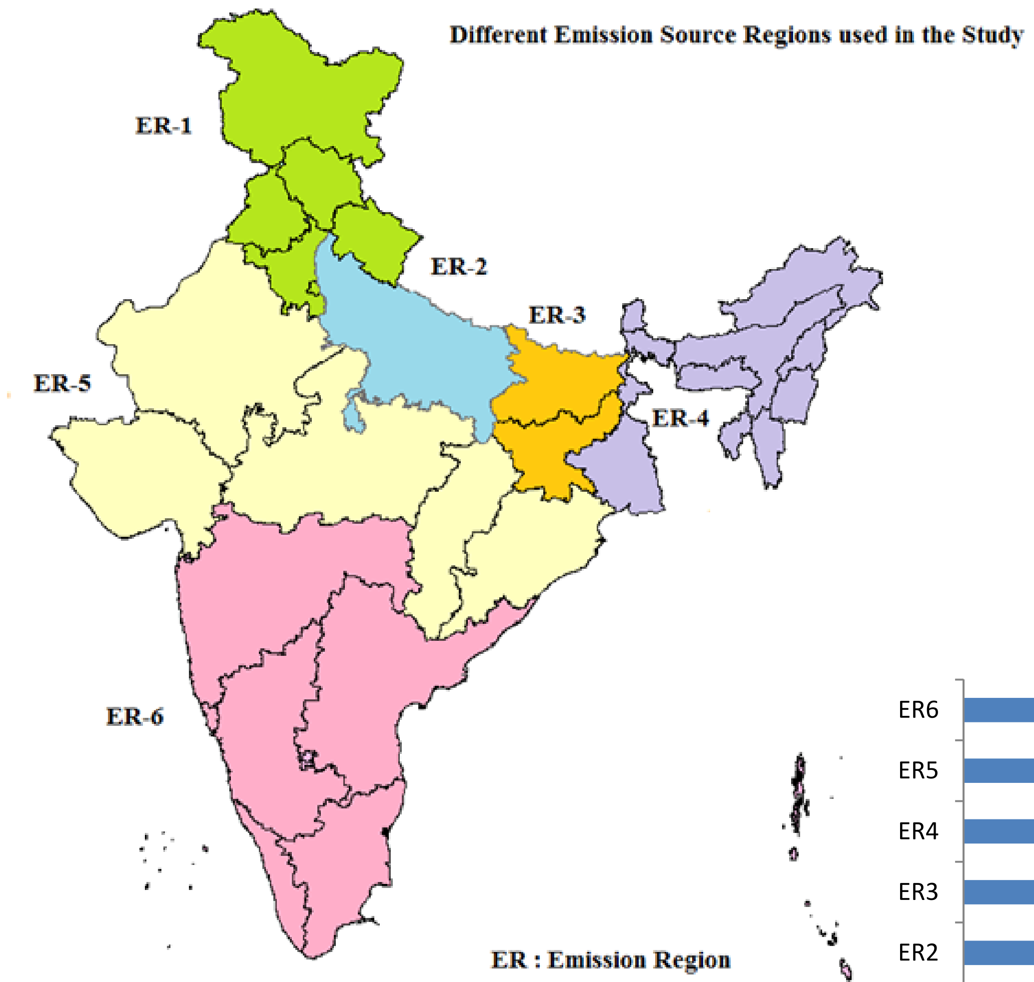


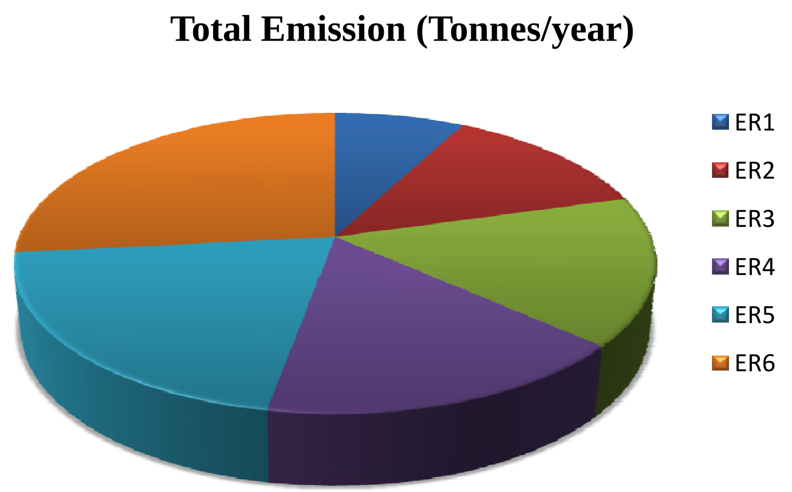


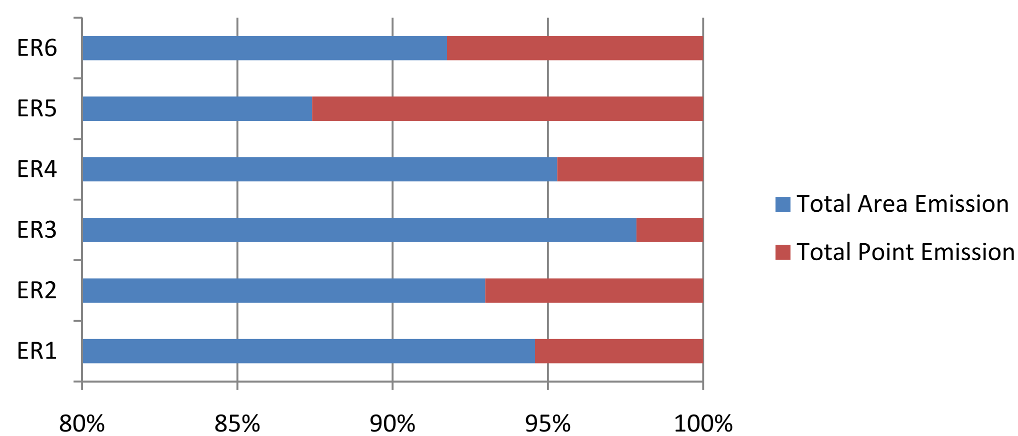
Study Region



LOCATION	6^{O}44'-35^{O}30' N	
	68^{O}7'-97^{O}25' E	
POPULATION	11,480 MILLION	
AREA	32,87,240 SQ. KM	
GDP	US$ 1.1 TRILLION	



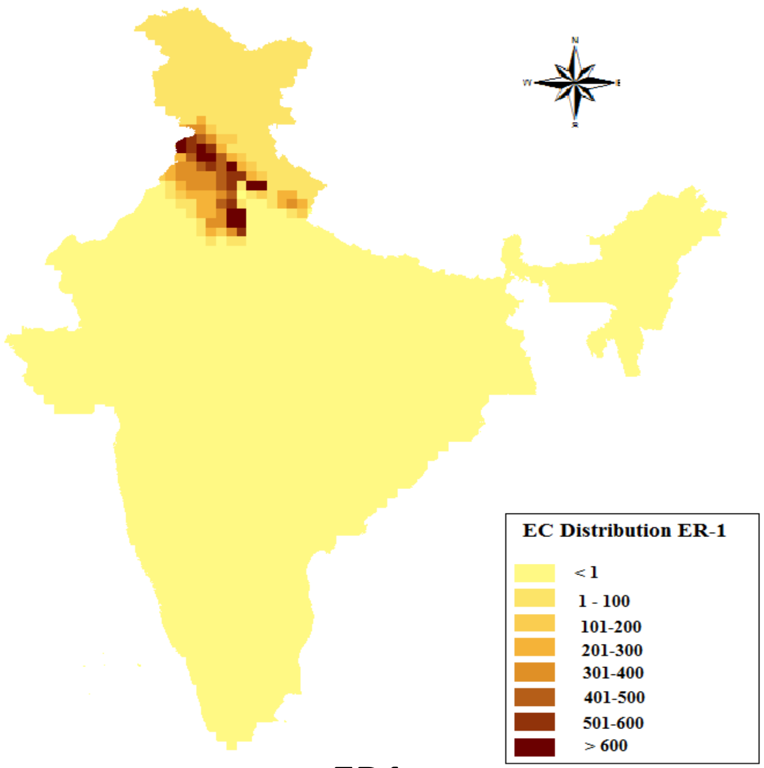


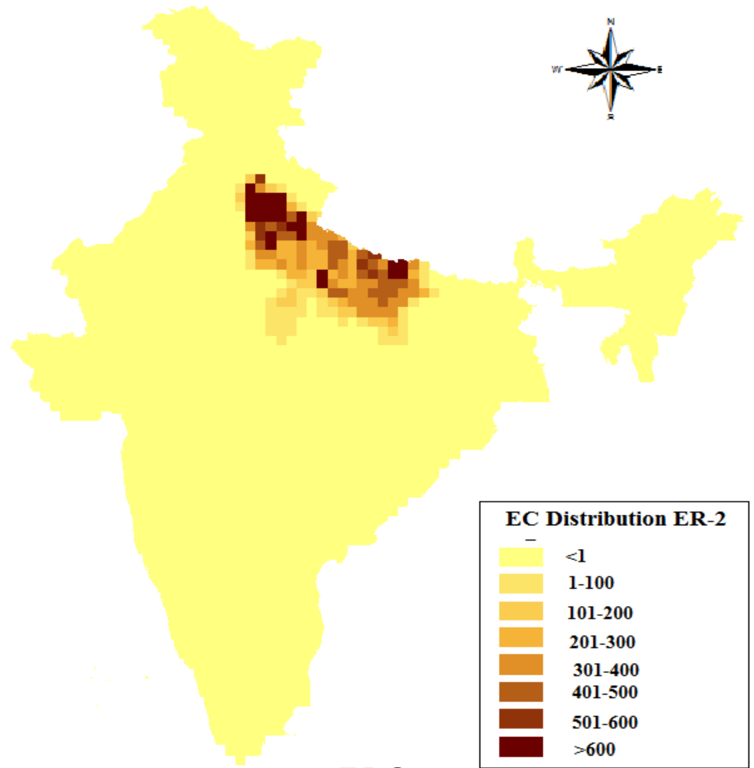


Different Emission Regions Used in the Study & Corresponding Point and Area Emissions

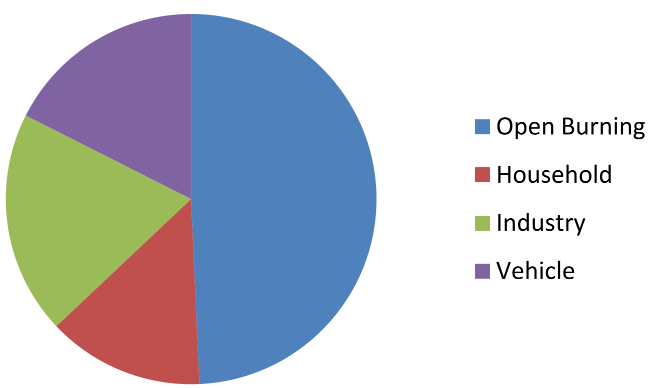
Area and Point Emissions from various ERs

Emission Region Label	States Included	Total Area Emissions (Tonnes/year)	Total Point Emission (Tonnes/year)	Total Emission (Tonnes/year)
ER1	J&K, Punjab, Himachal Pradesh, Haryana, Uttara khand, Delhi	38820	2223	41044
ER2	Uttar Pradesh	63982	4830	68812
ER3	Bihar, Jharkhand	83399	1829	85229
ER4	West Bengal, Sikkim, Assam, Arunachal Pradesh, Meghalaya, Mizoram, Nagaland, Manipur, Tripura	82845	4085	86930
ER5	Rajasthan, Gujarat, Madhya Pradesh, Chhattisgarh, Orissa	95430	13749	109179
ER6	Maharashtra, Goa, Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Andaman & Nicobar, Lakshadweep	130615	11742	142357
INDIA		**495092**	**38458**	**533550**

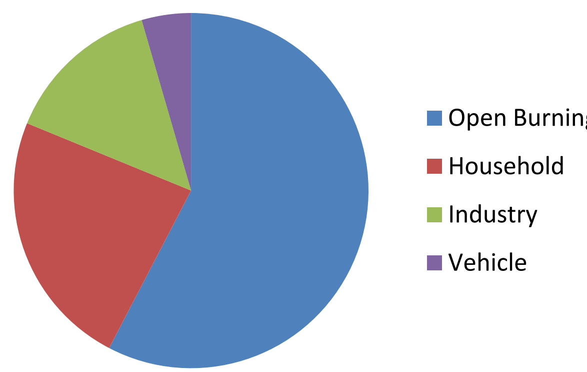




ER1

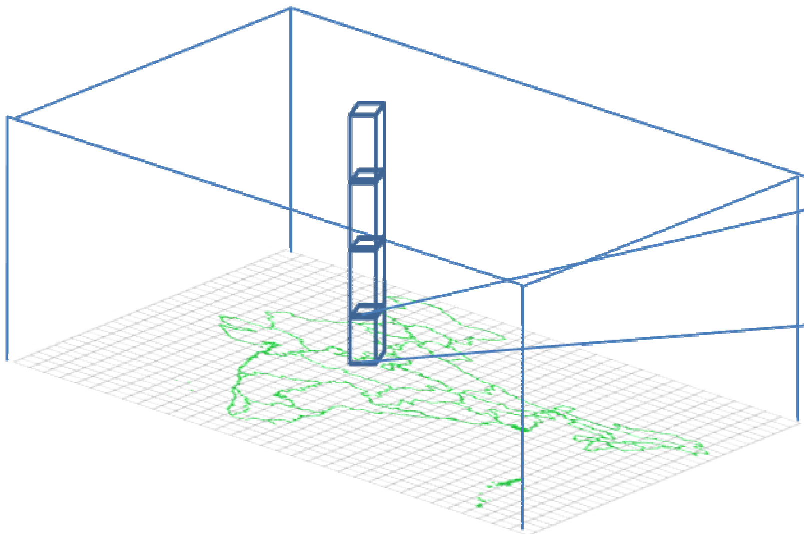


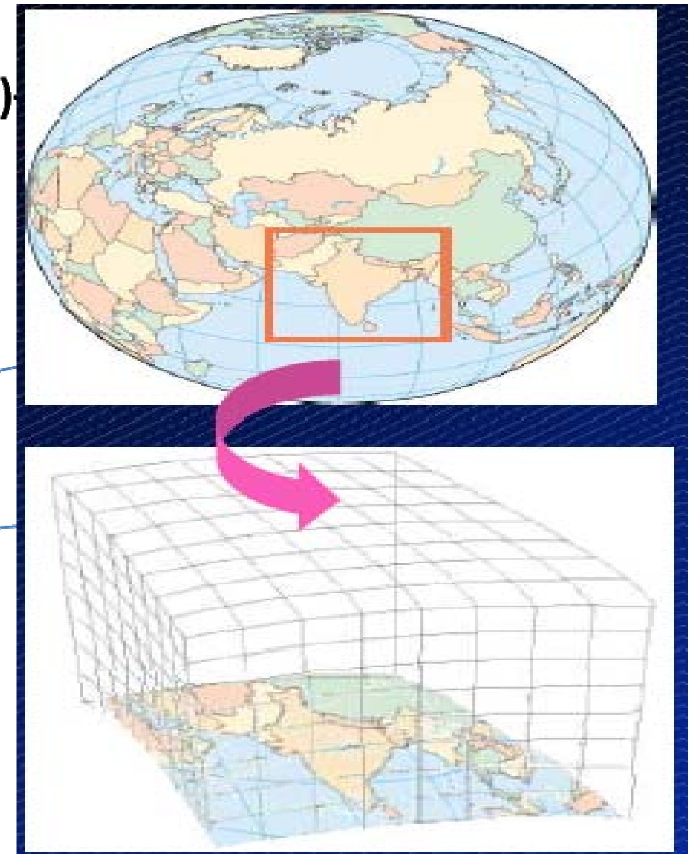
ER2



BC Distribution in ER1 and ER2 (values in Tonnes/year)

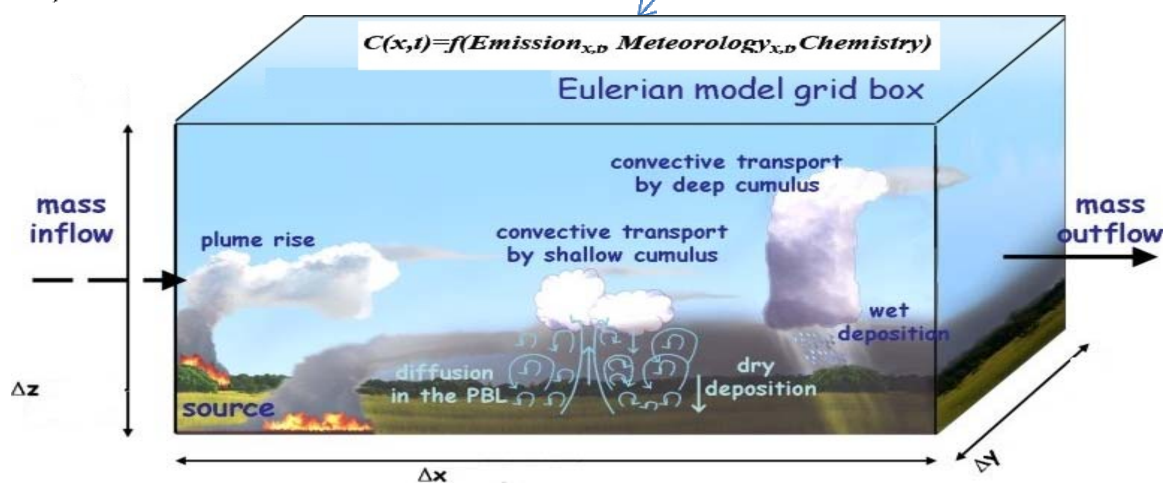
CAMx (Comprehensive Air Quality Model)



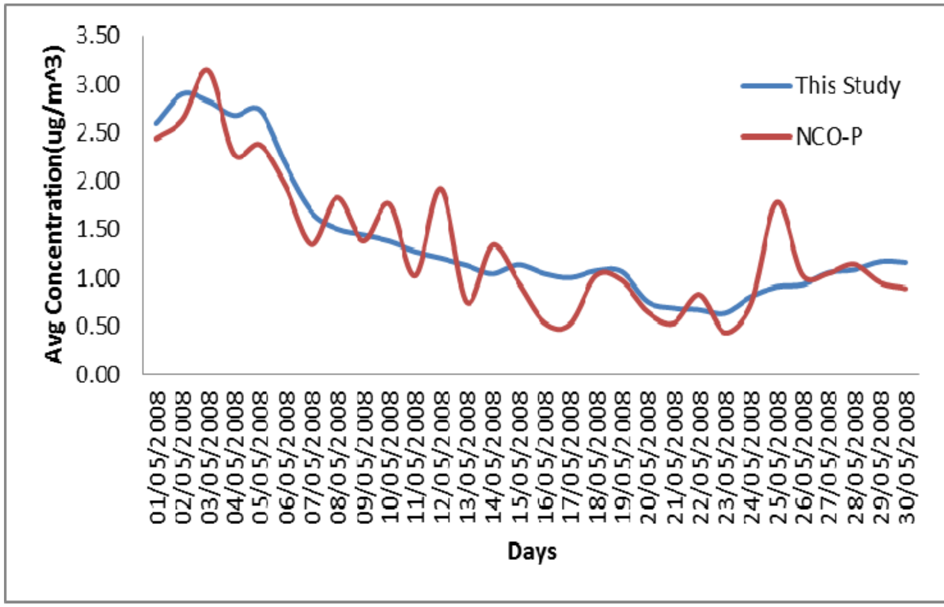


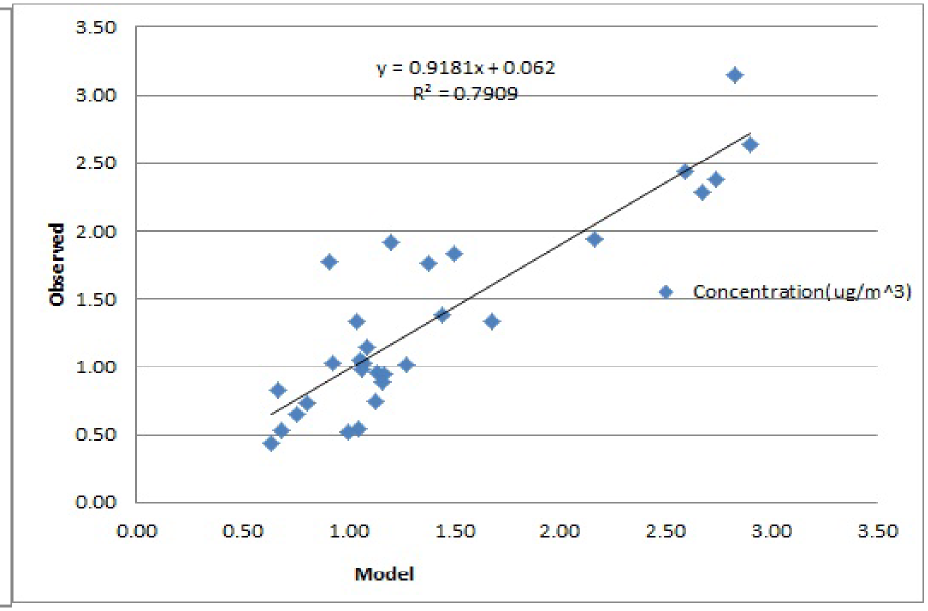
$$C(x,t)=f(Emission_{x,t}, Meteorology_{x,t}, Chemistry)$$

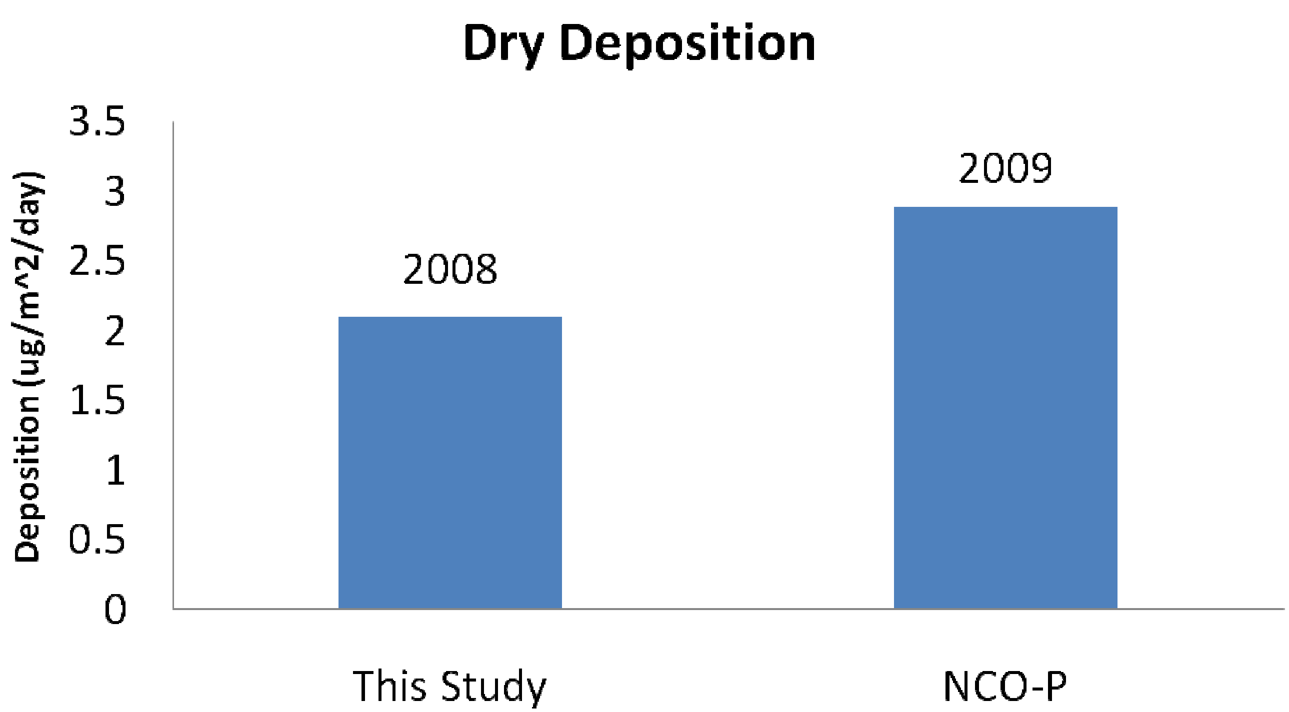
(photo source: Beig, 2006)




NCO-P

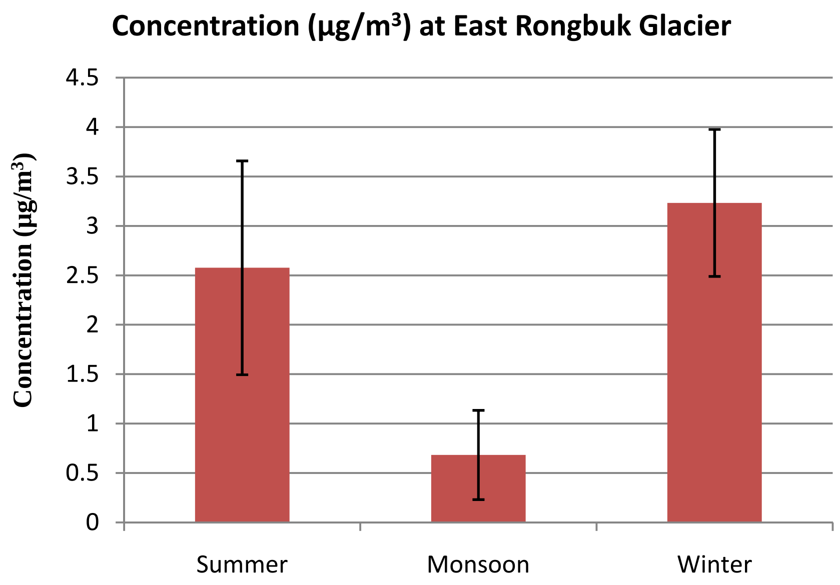

Avg Concentration(ug/m^3)
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
This Study
NCO-P
01/05/2008
02/05/2008
03/05/2008
04/05/2008
05/05/2008
06/05/2008
07/05/2008
08/05/2008
09/05/2008
10/05/2008
11/05/2008
12/05/2008
13/05/2008
14/05/2008
15/05/2008
16/05/2008
17/05/2008
18/05/2008
19/05/2008
20/05/2008
21/05/2008
22/05/2008
23/05/2008
24/05/2008
25/05/2008
26/05/2008
27/05/2008
28/05/2008
29/05/2008
30/05/2008
Days

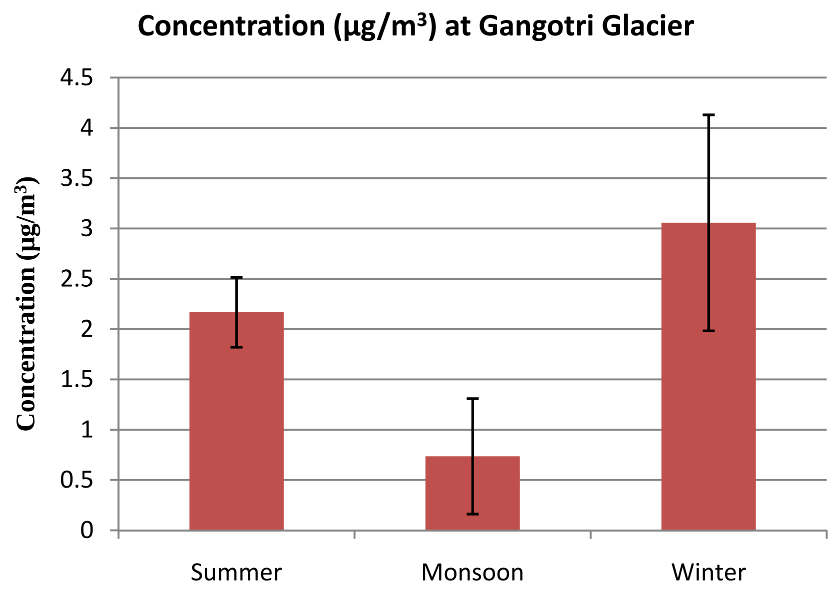

y = 0.9181x + 0.062
R² = 0.7909
Observed
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
Concentration(ug/m^3)
Model


Dry Deposition
Deposition (ug/m^2/day)
3.5
3
2.5
2
1.5
1
0.5
0
2008
2009
This Study
NCO-P

Concentrations at Receptor Sites due to Emissions from India

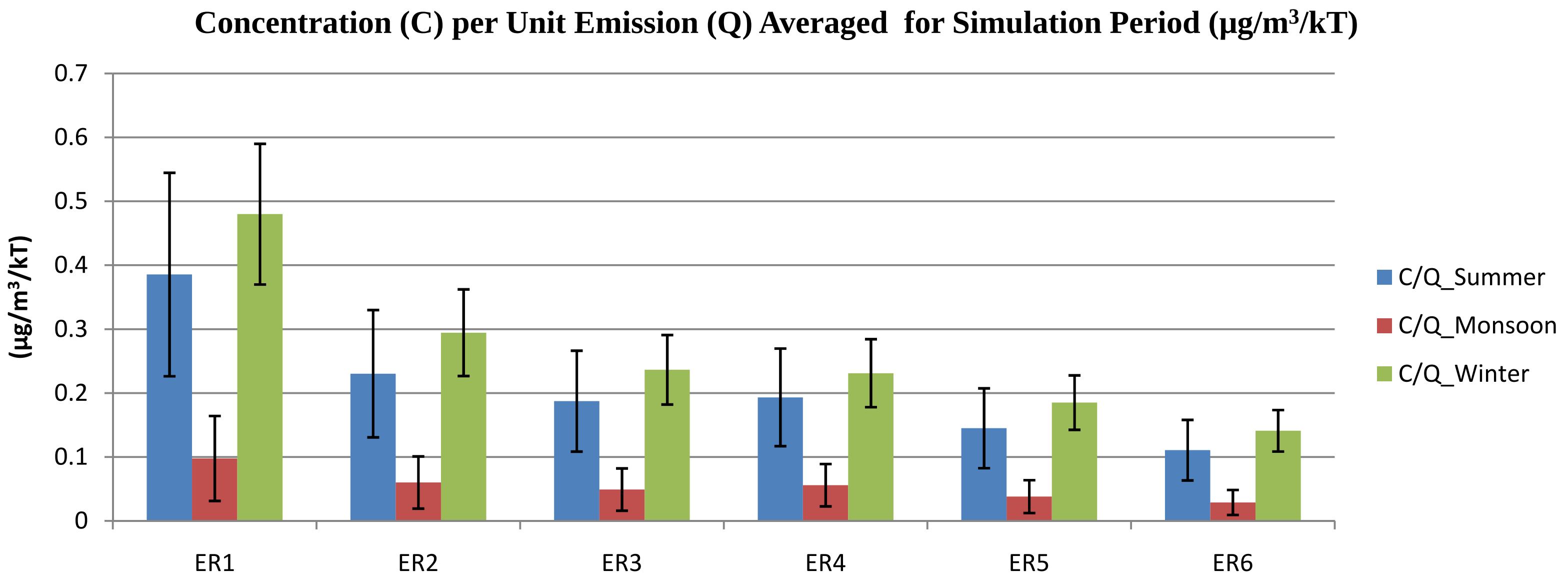
INDIA	Concentration in µg/m³		
Receptor Location	**Summer**	**Monsoon**	**Winter**
Gangotri Glacier	2.17±0.35	0.74±0.57	3.06±1.07
East Rongbuk Glacier	2.58±1.08	0.68±0.45	3.23±0.74





Maximum concentration values are during the summer and winter months, with very little concentration during the monsoon season.

East Rongbuk Glacier: Concentration



- Surprisingly, the normalized concentration value is maximum from ER1. Possible explanations:
  - the trajectory analysis show that the mid tropospheric air mass flows from ER1 directly towards the East Rongbuk Glacier, thus may carry pollutants along its path
  - average height of emissions in ER1 is more compared to other ERs
- The emissions from ER2, ER3 & ER4 contribute almost equally to the concentration at East Rongbuk

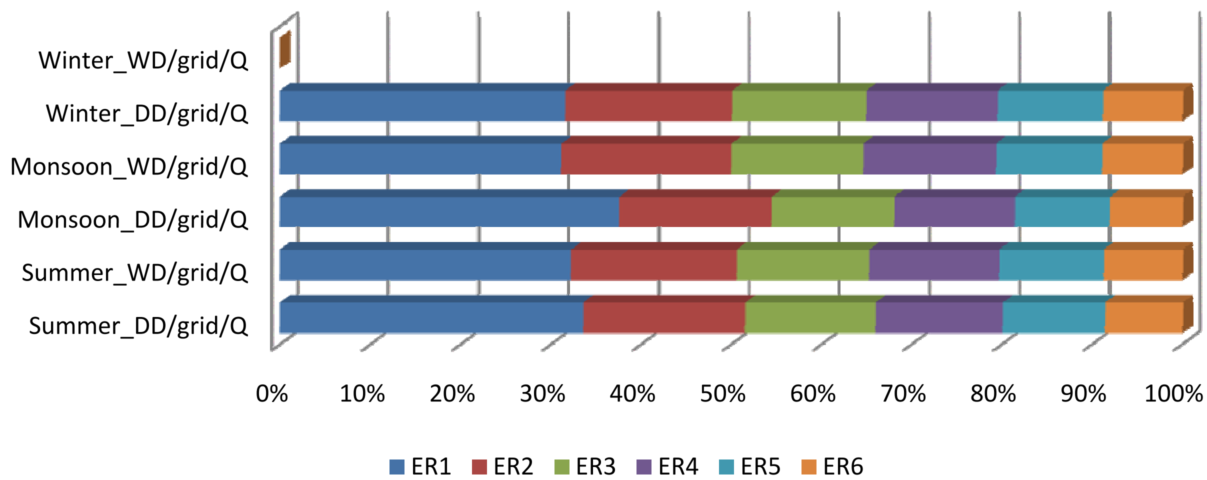
Comparison of Dry and Wet Deposition at Gangotri

Zone	$(Dry:Wet)_S$	$(Dry:Wet)_M$	$(Dry:Wet)_W$
ER1	1:36	1:230	1:0
ER2	1:38	1:309	1:0
ER3	1:38	1:298	1:0
ER4	1:38	1:305	1:0
ER5	1:38	1:308	1:0
ER6	1:38	1:309	1:0

Subscripts S, M and W denote Summer, Monsoon and Winter respectively

Regional Contribution to Net Deposition Fluxes at Gangotri Glacier

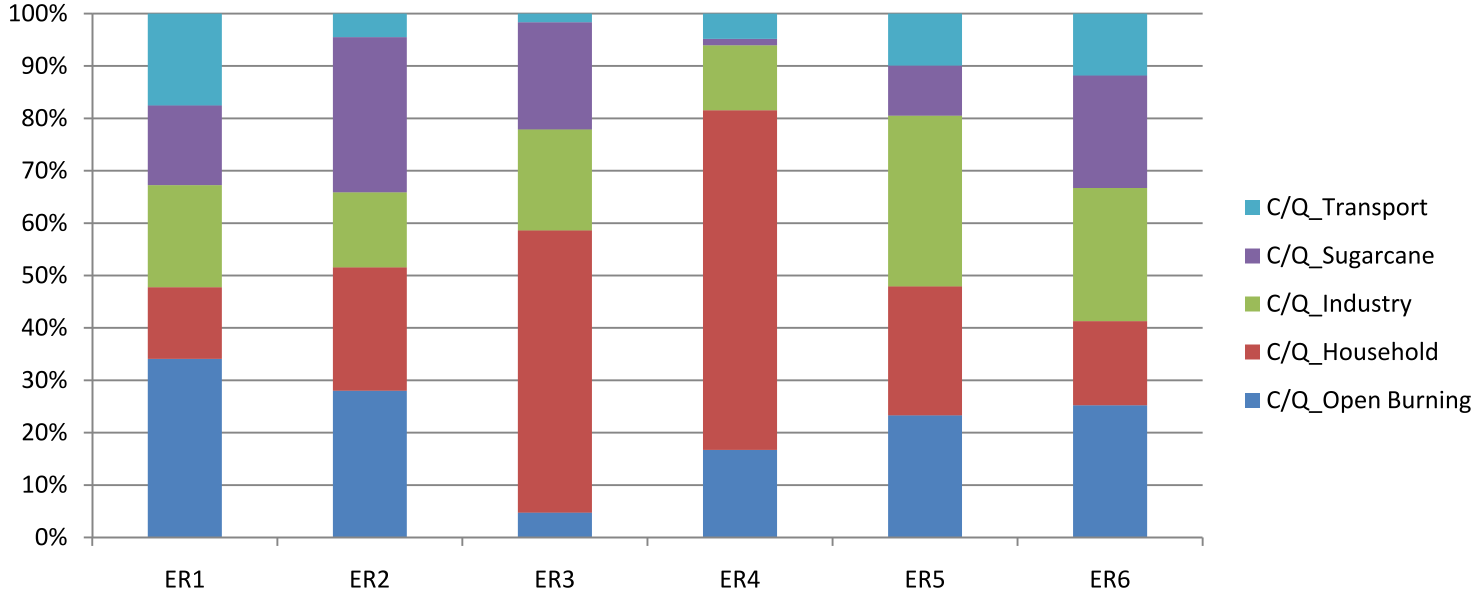
Contribution of each Emission Region (ER) to Dry & Wet Deposition



As before, it is easily observed that ER1, ER2, ER3, ER4 which represent only ~50% of the total emissions contribute approximately 80% of the total deposition

Control Strategies

- **Sector Wise Contribution to BC concentration on the Receptor Sites**



Here, we have segregated sugarcane industry because emissions from bagasse Burning were considerably high. As could be observed, transport sector is important from ER1

Control Strategies… continued

- Order of preference for BC control over the Himalayas

Emission Region	1st preference	2nd preference
ER1	Open Burning	Industry
ER2	Sugarcane Industry	Open Burning + Household
ER3	Household	Industry
ER4	Household	Open Burning

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

Control Strategies… continued

Demand Scenario 1- Business as usual (current growth & usage rates are used) (The study used 2005-06 as base year)

Year	Number of households using LPG (millions)			Proportion of total households using LPG (%)		
	Rural	Urban	Total	Rural	Urban	Total
2005-06	10.91	44.87	55.78	7.27	72.97	26.36
2010-11	15.17	63.38	78.56	9.30	90.00	33.64
2015-16	21.10	72.59	93.69	11.91	90.00	36.35

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.)

Year	Number of households using LPG (millions)			Proportion of total households using LPG (%)		
	Rural	Urban	Total	Rural	Urban	Total
2010-11	20.67	63.38	84.06	12.68	90.00	36.00
2015-16	39.17	72.59	111.76	22.12	90.00	43.36

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 BC emission reductions from ER2, ER3 and ER4

Control Strategies… continued

- If we assume 11% increase in LPG consumption over next 5 years in rural area, we can decrease BC emissions by ~ 7% from the domestic sector in ER3 and ER4
- Under some practices, if open burning decreases by 50% in ER1 and ER2, we can expect a 14-17% decrease in BC emissions & thus corresponding decrease in BC concentration
- Although not considered here, if the burning of bagasse is diverted to other uses (like in pulp and paper industry, renewable sector), it will also decrease BC concentration
- Vehicular Contribution from ER1 ~ 20 percent – vehicle impact can be important.

Thank You !!!!