Presented at "Black Carbon Emissions and Climate Change: A Technical Workshop," San Diego, USA, October 13-15, 2004

UNCERTAINTIES IN BLACK CARBON EMISSIONS AND MODEL PREDICTIONS: A SOUTH ASIAN PERSPECTIVE

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OUTLINE

Emissions estimation: industrial/transport, residential, open burning

- **Level of sectoral detail**
- **Fuel composition and technology information**
- **Developing / measuring emission factors**
- **Assumptions in spatial distributions**
- **Seasonal and interannual variability**
- **Estimated uncertainties and strategies for their reduction**

BC transport and radiative forcing using a general circulation model

- **Evaluation of model predictions**
- **Sensitivity study**
- **Optical depth and radiative forcing**

EMISSIONS ESTIMATION APPROACH

-emission rates (kg y^{-1}) or densities (kg km^{-2} y^{-1}) from fuel consumptions and specific emissions (or emission factors).

-at the global, national, regional, urban level (0.5-1 km for urban; 25-100 km for regional and global).

-Includes, in principle, all sources that emit into that atmosphere.

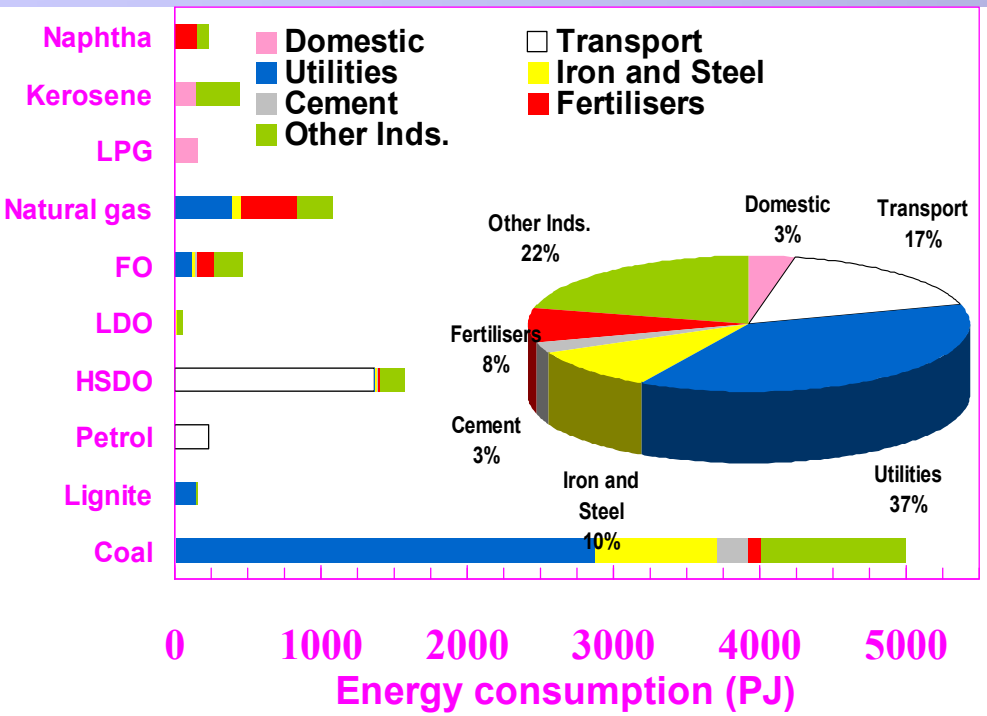
Emission Rate = *Activity Data* x *Pollutant Emission Factor*

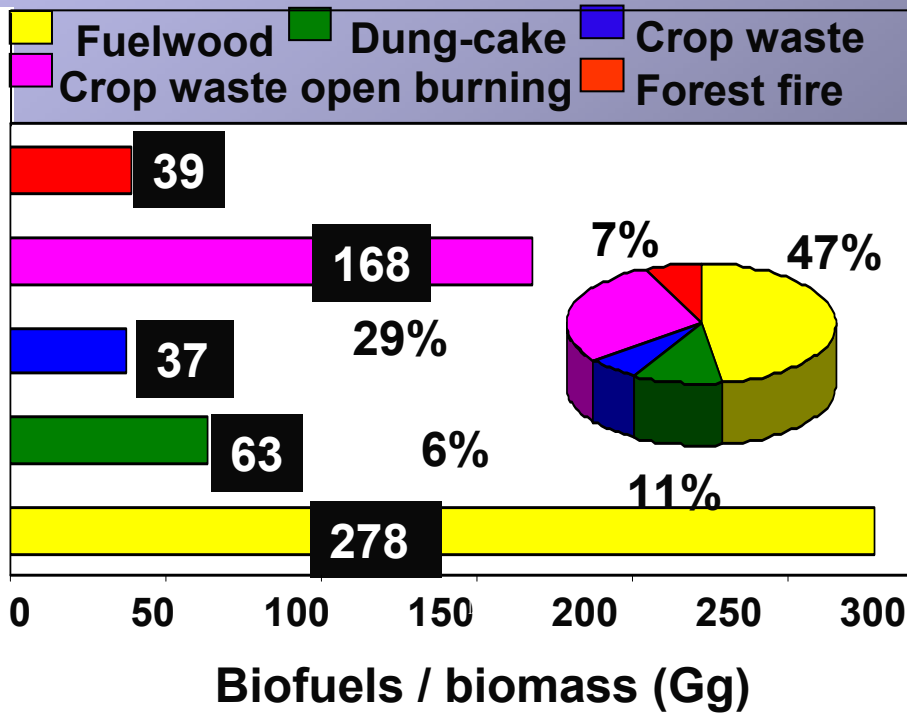
Activity Data:	Emission Factor:
- fuel used (Gg y^{-1})	kg pollutant (Gg fuel)$^{-1}$
- industrial production (Gg y^{-1})	kg pollutant (Gg product)$^{-1}$
- km y^{-1} travelled by vehicle	g pollutant (km)$^{-1}$

FUEL CONSUMPTION - INDIA

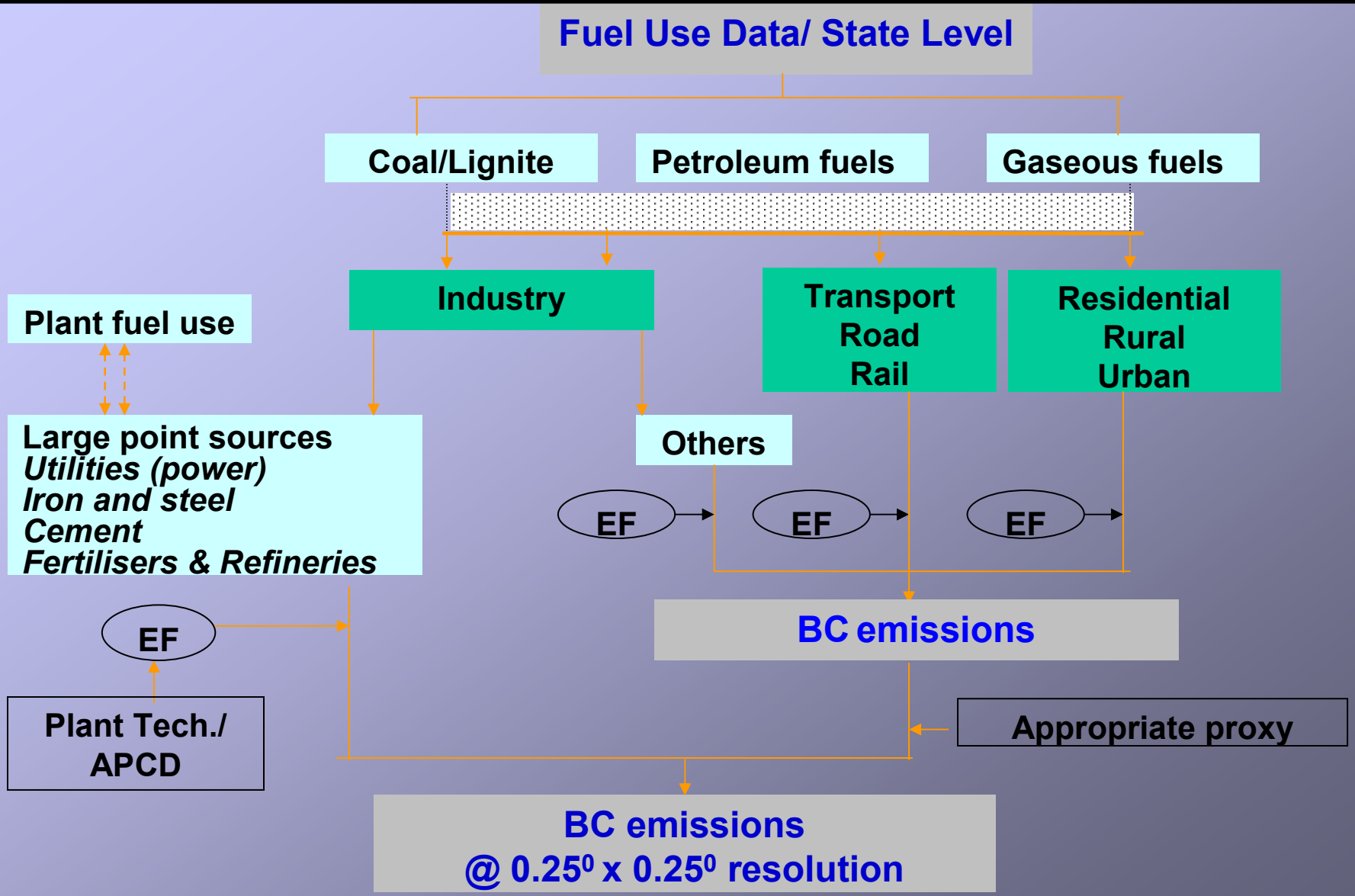
Fossil: 9,411 PJ (1 PJ = 10^{15} J)

Biofuel/biomass: 8,213 PJ





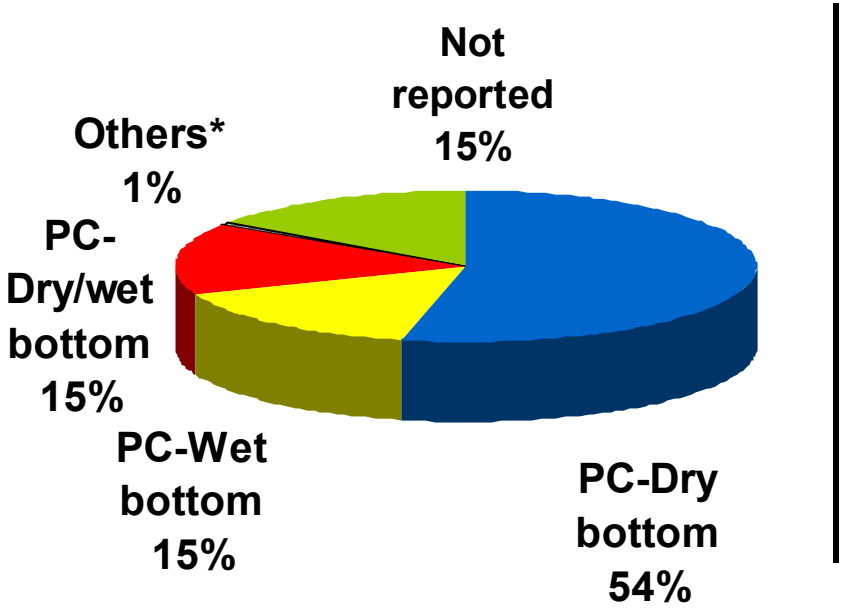
INDUSTRIAL/TRANSPORT: SECTORAL DETAIL



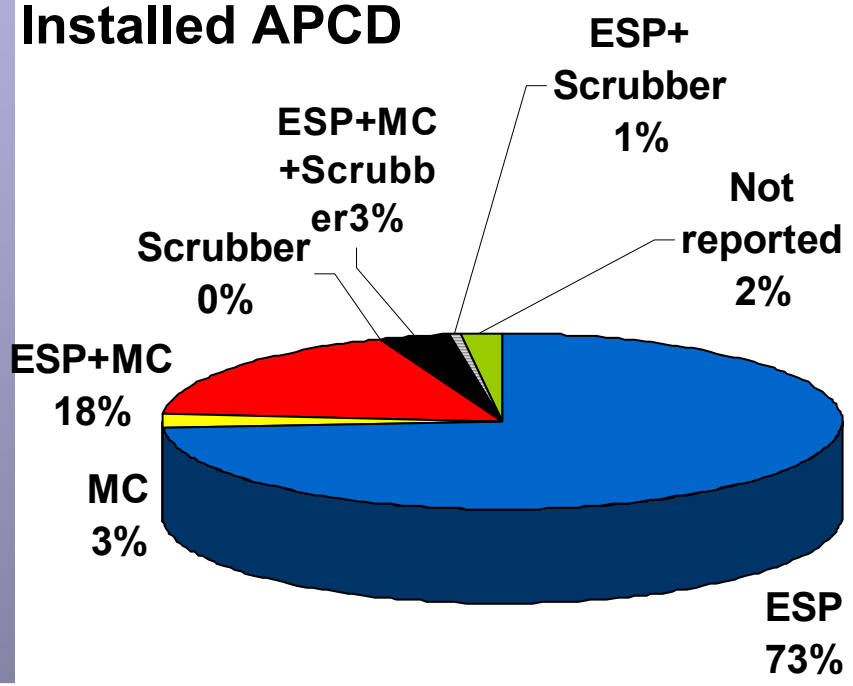
INDUSTRIAL/TRANSPORT: FUEL & TECHNOLOGY ANALYSIS

e.g. ELECTRIC UTILITIES

Boiler Type



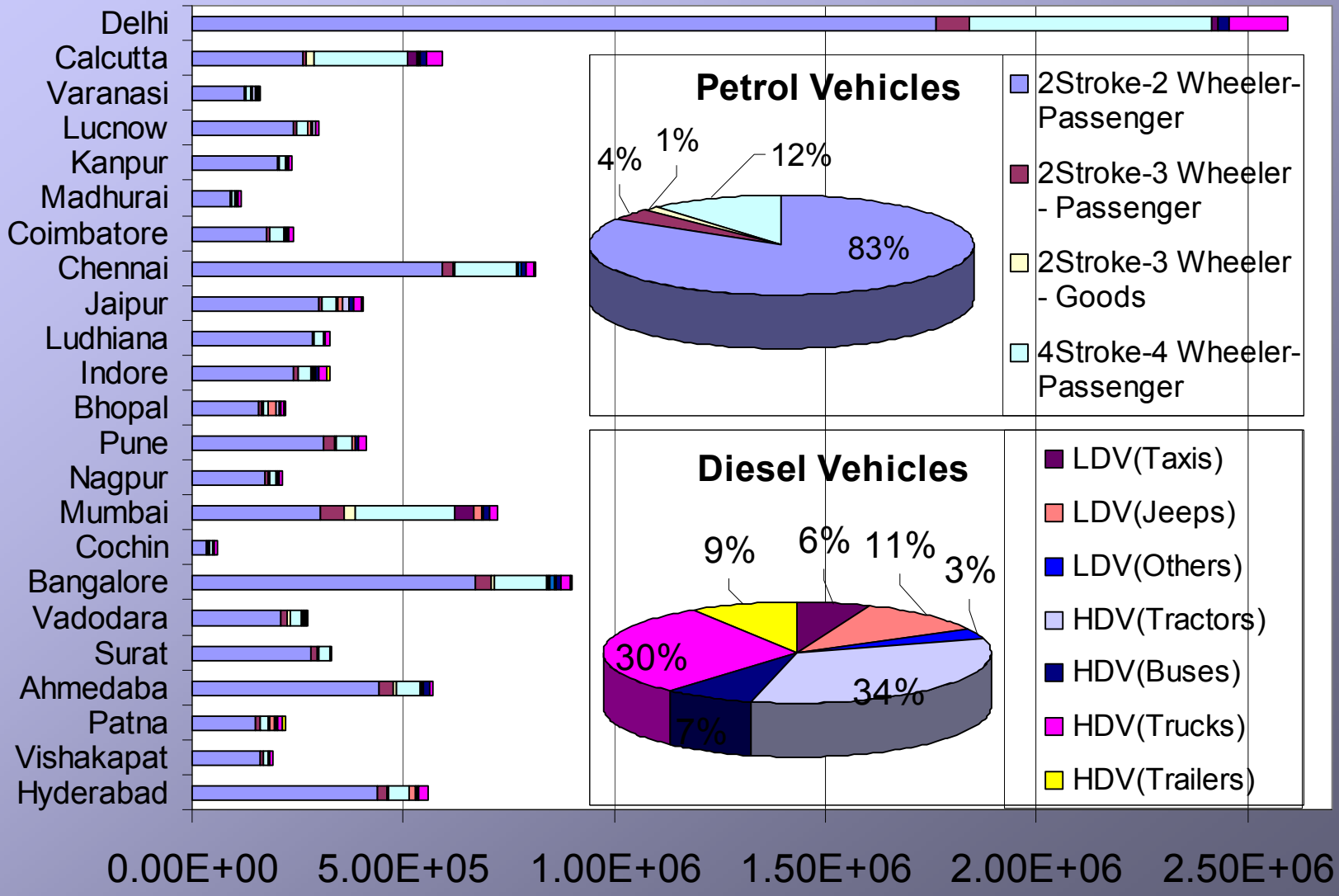
Installed APCD



INDUSTRIAL/TRANSPORT: FUEL & TECHNOLOGY ANALYSIS

e.g. TRANSPORT

Vehicle count in 22 major cities



INDUSTRIAL/TRANSPORT: EMISSION FACTORS

Size Specific PM Emission Factors for Coal Combustion in Dry Bottom Boilers

Cumulative Mass % ≤ Stated Size				Cumulative Emission Factor g kg^{-1}		
Particle Size (μm)	Un-controlled	Multiple Cyclone	ESP	Un-controlled	Multiple Cyclone	ESP
15	32	54	79	1.60A	0.54A	0.032A
10	23	29	67	1.15A	0.29A	0.027A
6	17	14	50	0.85A	0.14A	0.012A
2.5	6	3	29	0.30A	0.03A	0.012A
1.25	2	1	17	0.10A	0.01A	0.005A
1.00	2	1	14	0.10A	0.01A	0.005A
0.625	1	1	12	0.05A	0.01A	0.005A

** ESP: Electrostatic Precipitators*

A= coal ash weight percent, as fired. For example, if coal ash weight is 40%, then A=40.

Source: U.S. EPA AP-42 Compilation of emissions factors for stationary sources

BC/PM ratios for Coal Boilers: 2.2-6.4% **(Henry and Knapp, 1980; Shibaoka, 1986; Veranth, 2000)**

INDUSTRIAL/TRANSPORT: EMISSION FACTORS

Road Transport:

PM, BC/PM, OC/PM Literature reported measurements for diesel (LDV, HDV) and petroleum (leaded, unleaded) vehicles

Rail Transport: Values reported by *US EPA* [1998].

Fuel/vehicle type	PM avg. ($g\ kg^{-1}$)	BC avg. (% of PM)	OC avg. (% of PM)
Diesel/ HDV [a]	4.62	42	36
Diesel/ LDV [b]	3.13	67	24
Leaded petrol	0.84	6	47
Un-leaded petrol/WCC [c]	0.36	23	73

[a]LDV: heavy duty vehicles; [b] LDV: light duty vehicles; [c] WCC: without catalytic converters

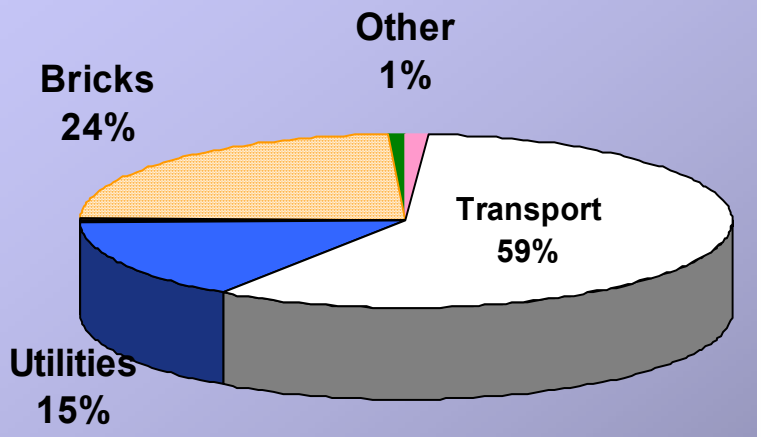
INDUSTRIAL/TRANSPORT: SPATIAL & SEASONAL DISTRIBUTIONS

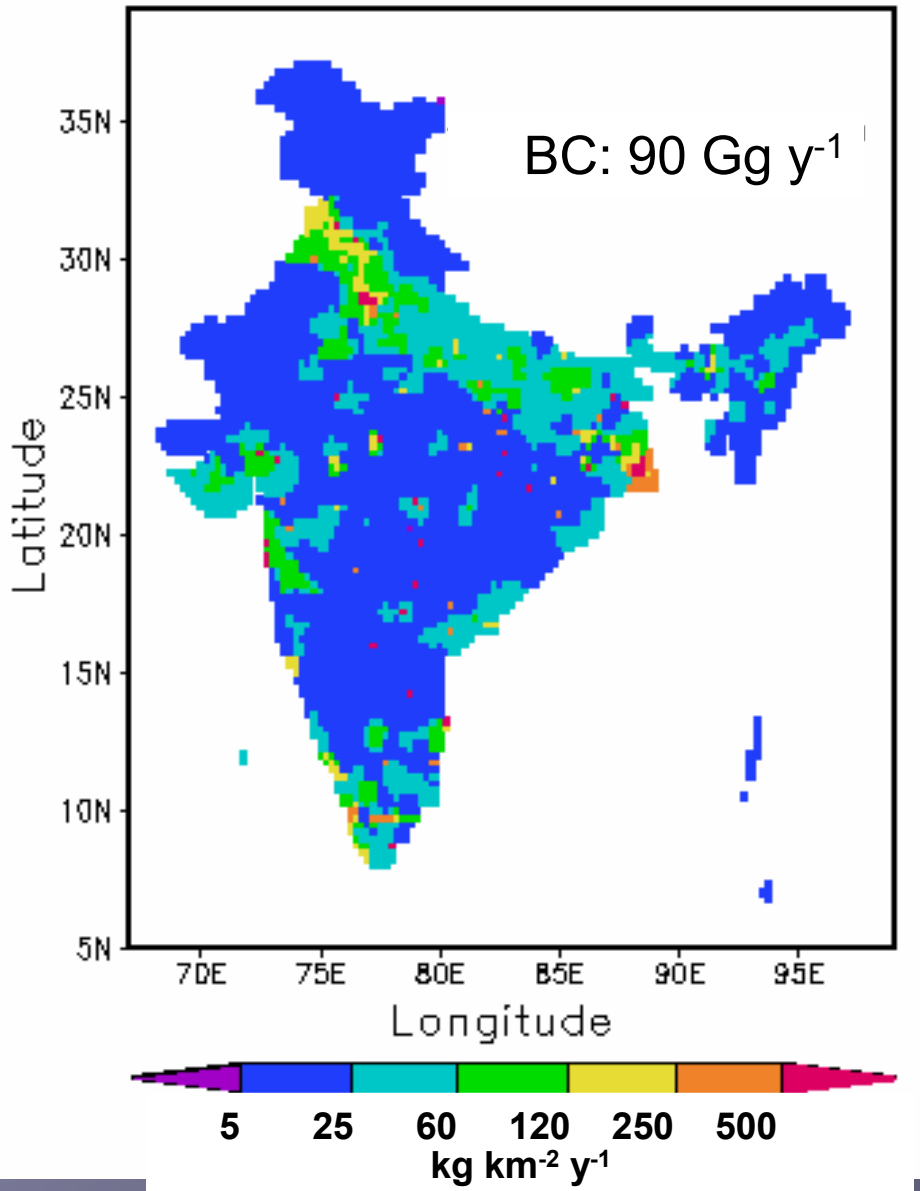
Assumed no seasonal variability in industrial and transport emissions.

Proxies from state to district and down to 25 km x 25 km resolution

- **Point sources: - district power generation, cement / steel / industrial production.**
- **Transport: road - vehicle population in 22 cities.**
  - balance district urban population.
  rail - district geographical area.

INDUSTRIAL/TRANSPORT: BLACK CARBON EMISSIONS





INDUSTRIAL/TRANSPORT: UNCERTAINTIES

- **Activity data statistics :** 20-40%
- **Emission factors :**
  - applicability of non-region-specific emission factors?
  - validation needed through measurements.
  - factor of 4-5 (300-400%).
- **Needs :**

  Transport

  > modelled emission factors.

  > on-road emissions measurement (mixed fleet, urban, interstate).

  > possible fuel-adulteration effects on emissions.

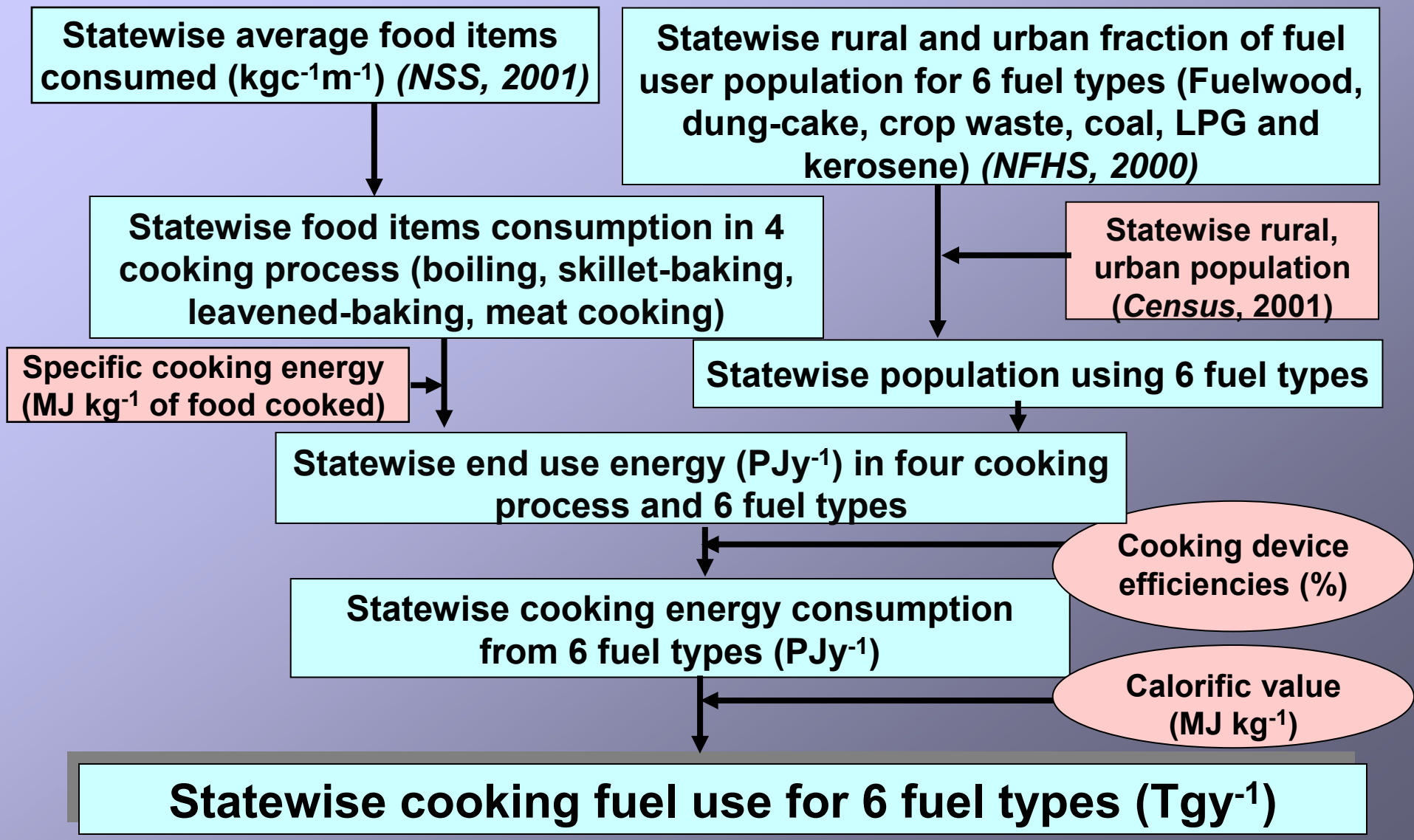
  Brick kilns

  > emissions from representative kiln types.

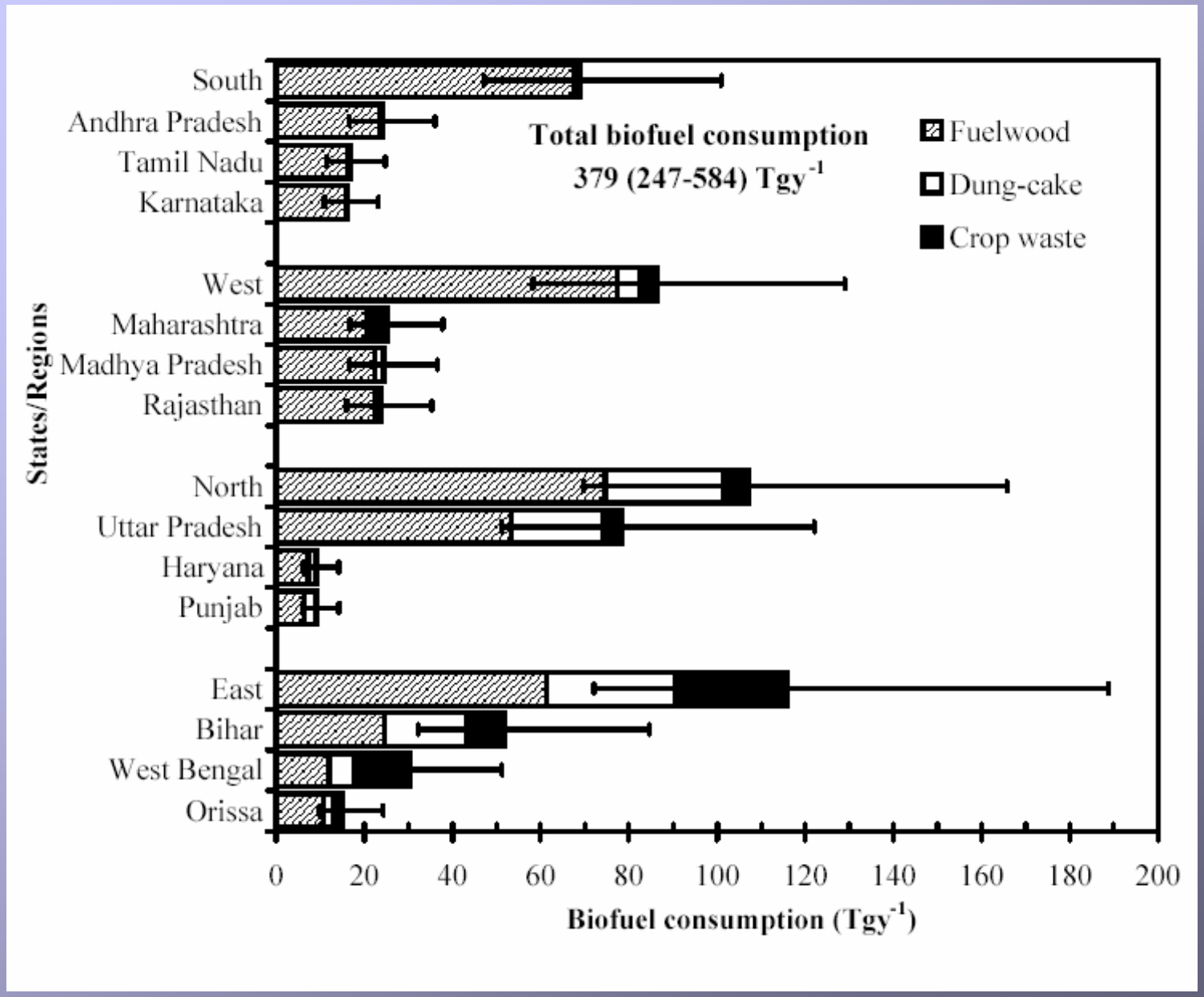
RESIDENTIAL

- Energy surveys : high uncertainty and low representative-ness for biofuels (kg capita^{-1} day^{-1}).
- User population : not estimated.
- Unquantifiable uncertainties.
- Highly uncertain emission factors for biofuels.

RESIDENTIAL: SECTORAL/TECHNOLOGY DETAIL



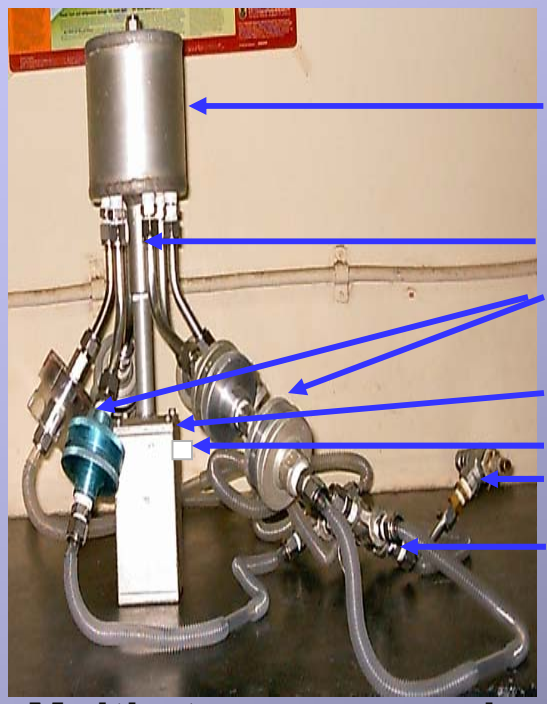
RESIDENTIAL: BIOFUEL ACTIVITY DATA



RESIDENTIAL: EMISSION FACTOR MEASUREMENT

Dilution sampler

Burn cycle



Multi-stream aerosol sampler

Stove fuel system used

- Traditional single pot mud stove
- 5-wood species, dung-cake and 10-crop waste types
- High and low power phases

Dilution sampler

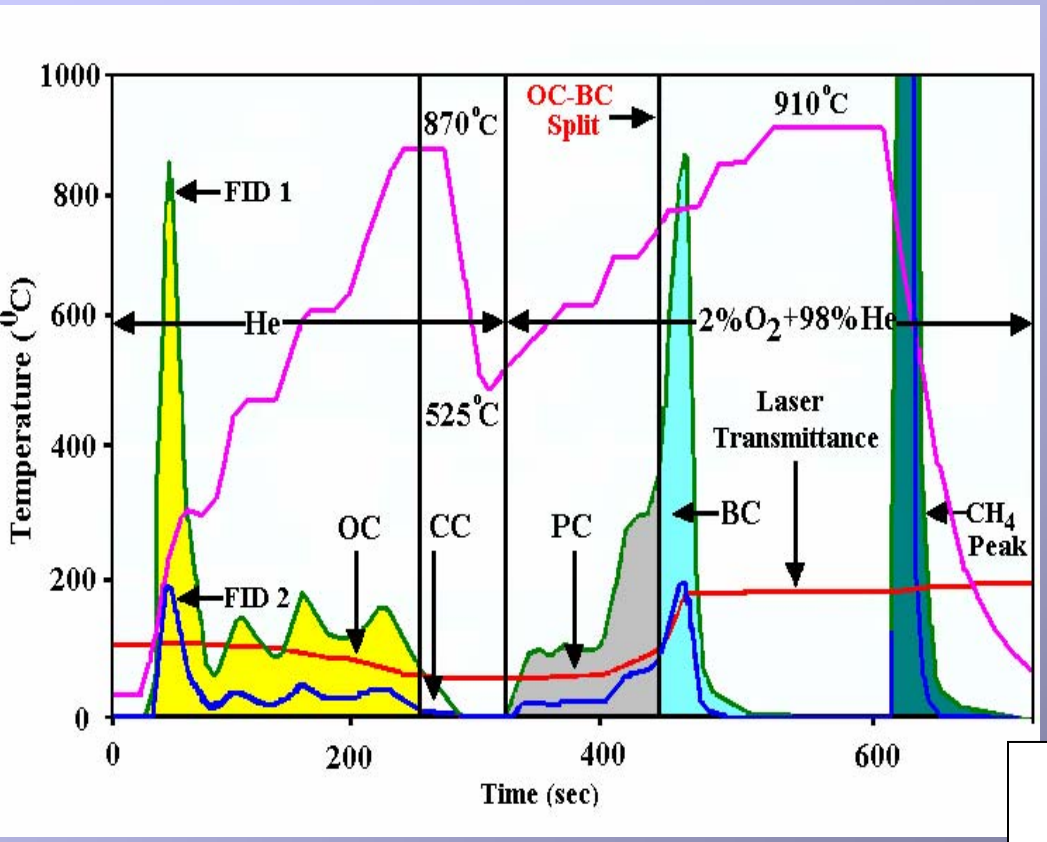
- Optimized for aerosol stabilization
- Mass of fuel, duct velocity, temperatures in combustion zone, duct and plenum recorded each minute

Pollutant measurement

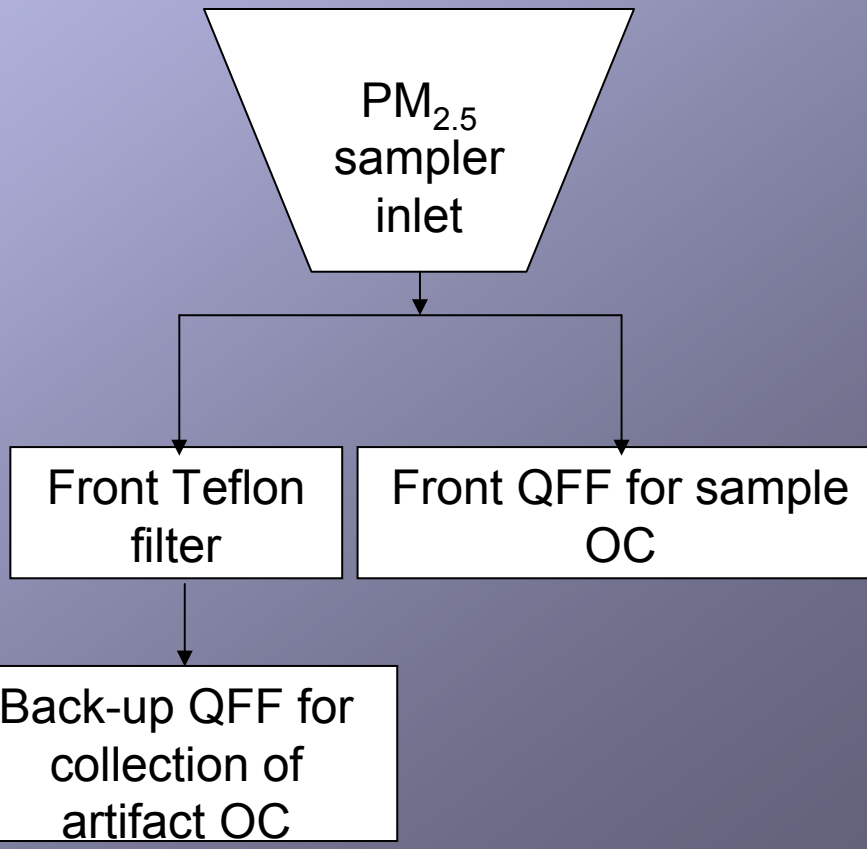
- $PM_{2.5}$: Multi-stream cyclone sampler
- OC-BC: Thermal optical transmittance (S. California Particle Centre and Supersite)
- SO_2, NO_2, ions, trace elements and absorption

OC-EC MEASUREMENT

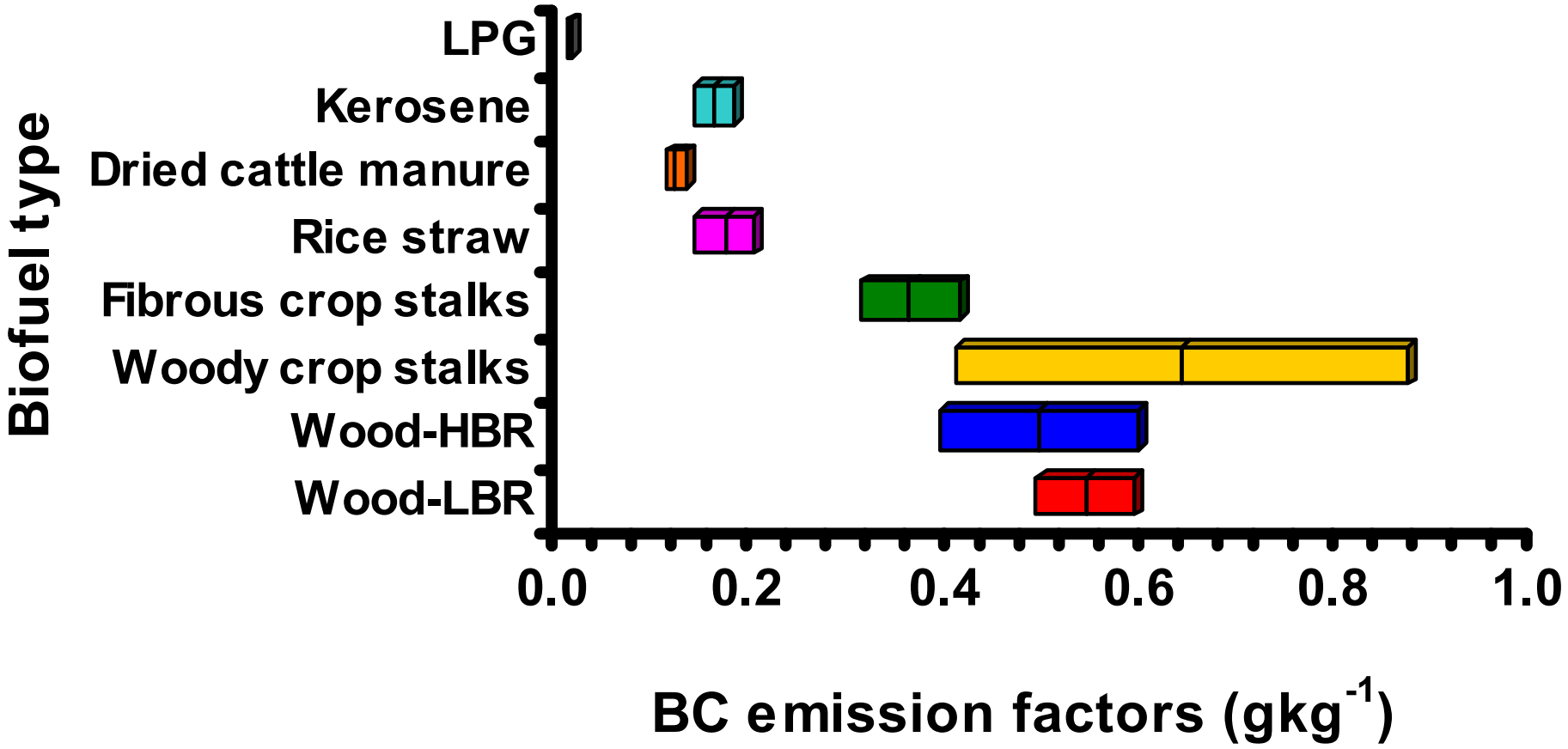
Typical thermogram



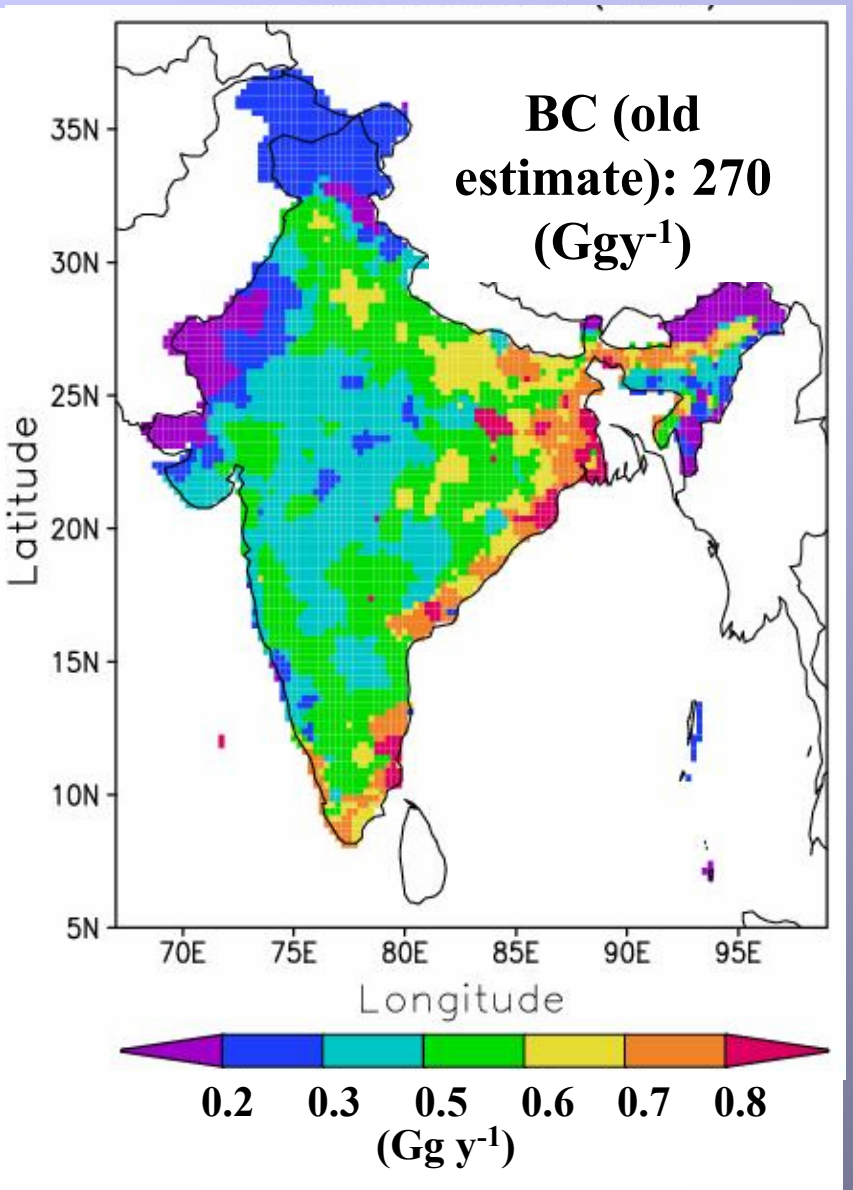
OC artifact measurement

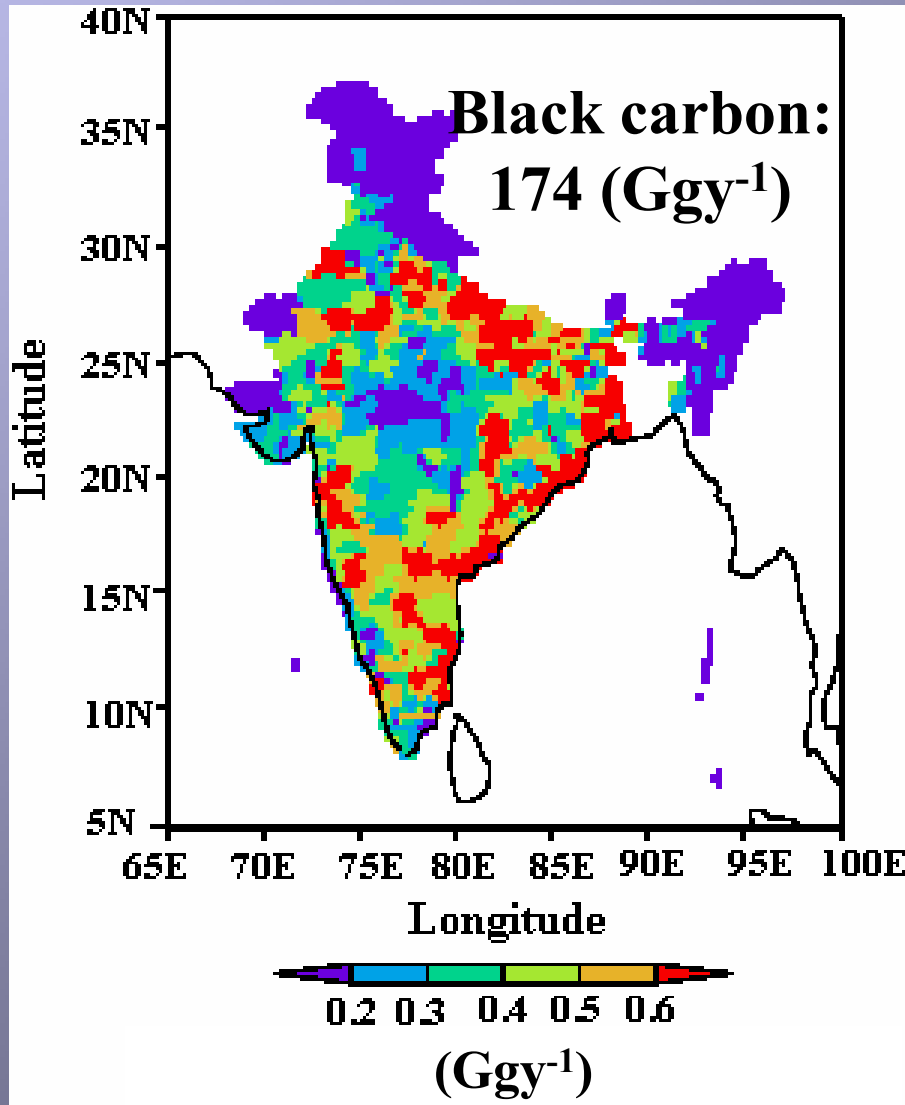


RESIDENTIAL: EMISSION FACTORS FROM COOKING



RESIDENTIAL: BLACK CARBON EMISSIONS



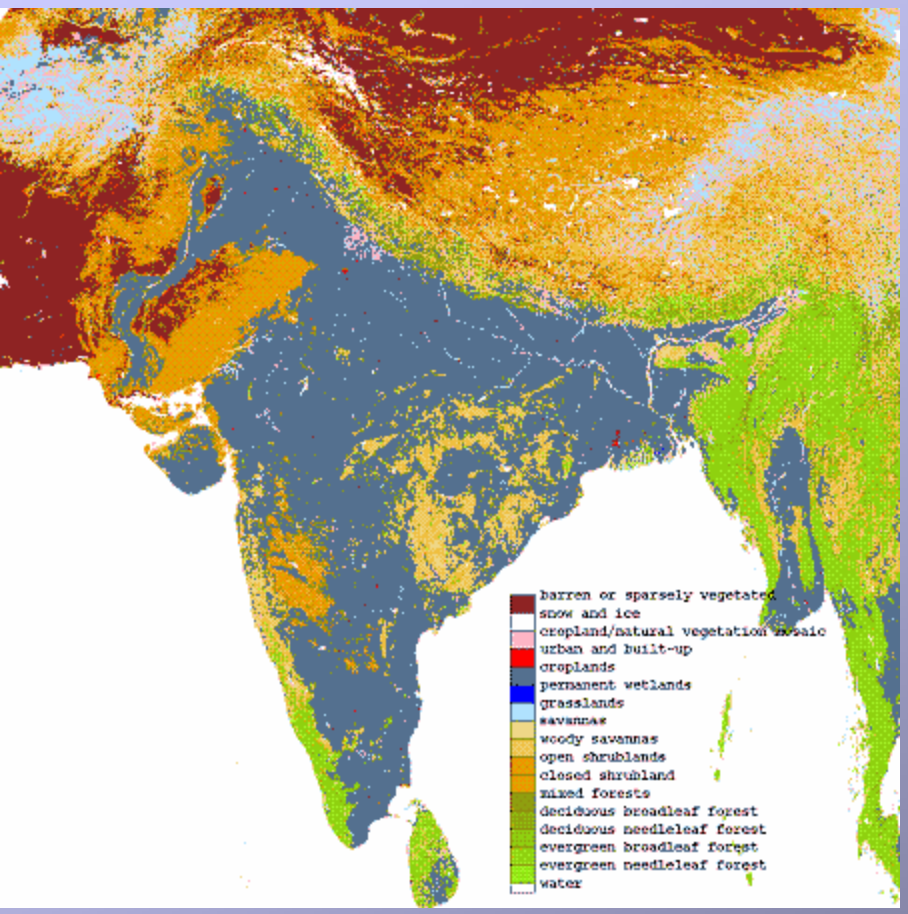


RESIDENTIAL: UNCERTAINTIES

- **Activity data statistics :**
  - **cooking (various fuel categories) ~45-85%**
- **Emission factors :**
  - **cooking (traditional stoves / various fuel categories) ~20-100%**
- **Needs :**
  - **water heating / space heating ~unknown**
  - **emission factors for mixed fuel use ”**
  - **emissions from improved cooking technologies ”**
  - **outdoor penetration of residential emissions ”**

OPEN BURNING

MODIS vegetation map



Forest / grassland / shrubland:

E = A . AFL . CE . EF

- uncertain A (area under different land types).
- uncertain AFL, CE.
- seasonal / interannual variability.
- shifting cultivation practices (Jhum)

Agricultural waste burning in croplands:

E = CP . RPR. F. DM. CE. EF

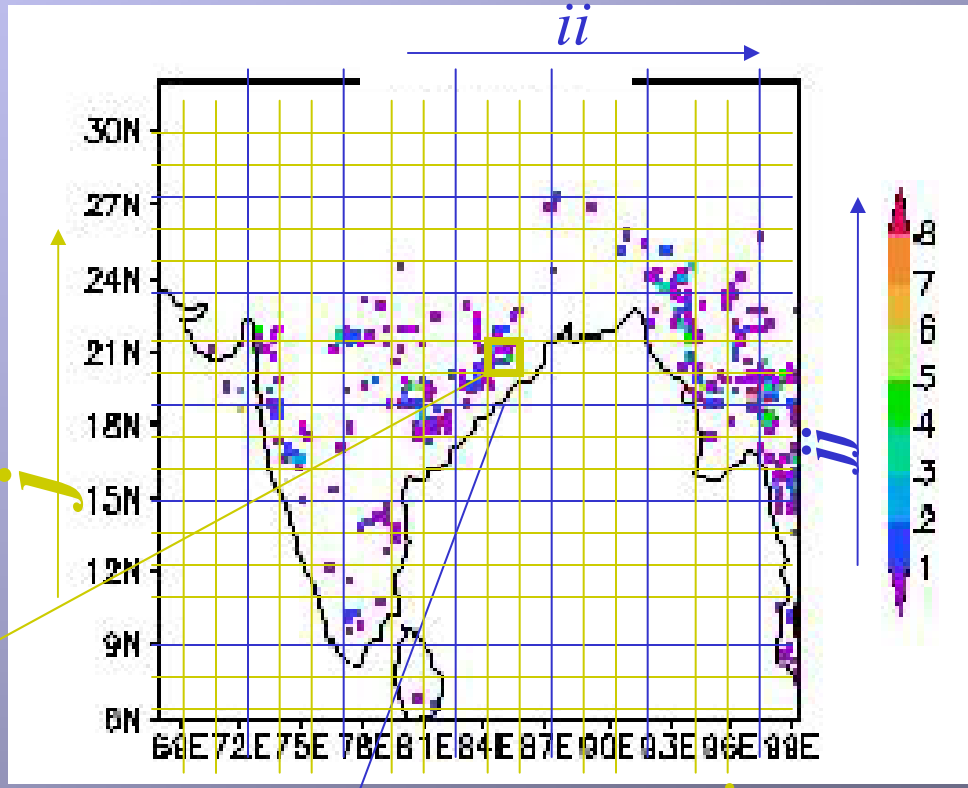
- uncertain F, CE.
- systematic spatial/temporal variation.

OPEN BURNING: INTERANNUAL-SEASONAL VARIABILITY

Integrating bottom-up and top-down approaches:

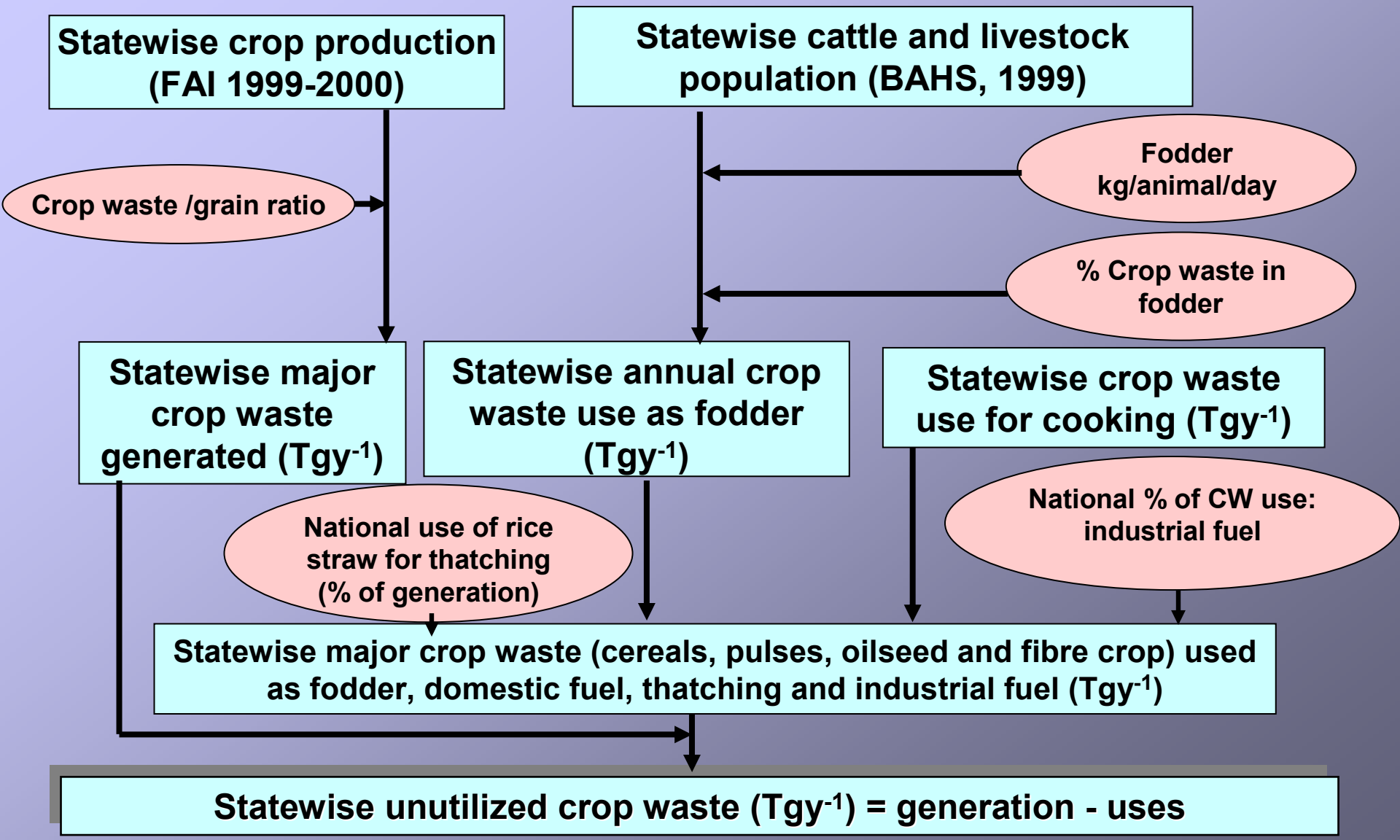
- biomass burnt from bottom up methods.
- temporal / spatial distribution from active fires and vegetation data.
- high resolution, co-location.

Annual Emissions per grid (bottom-up estimate)

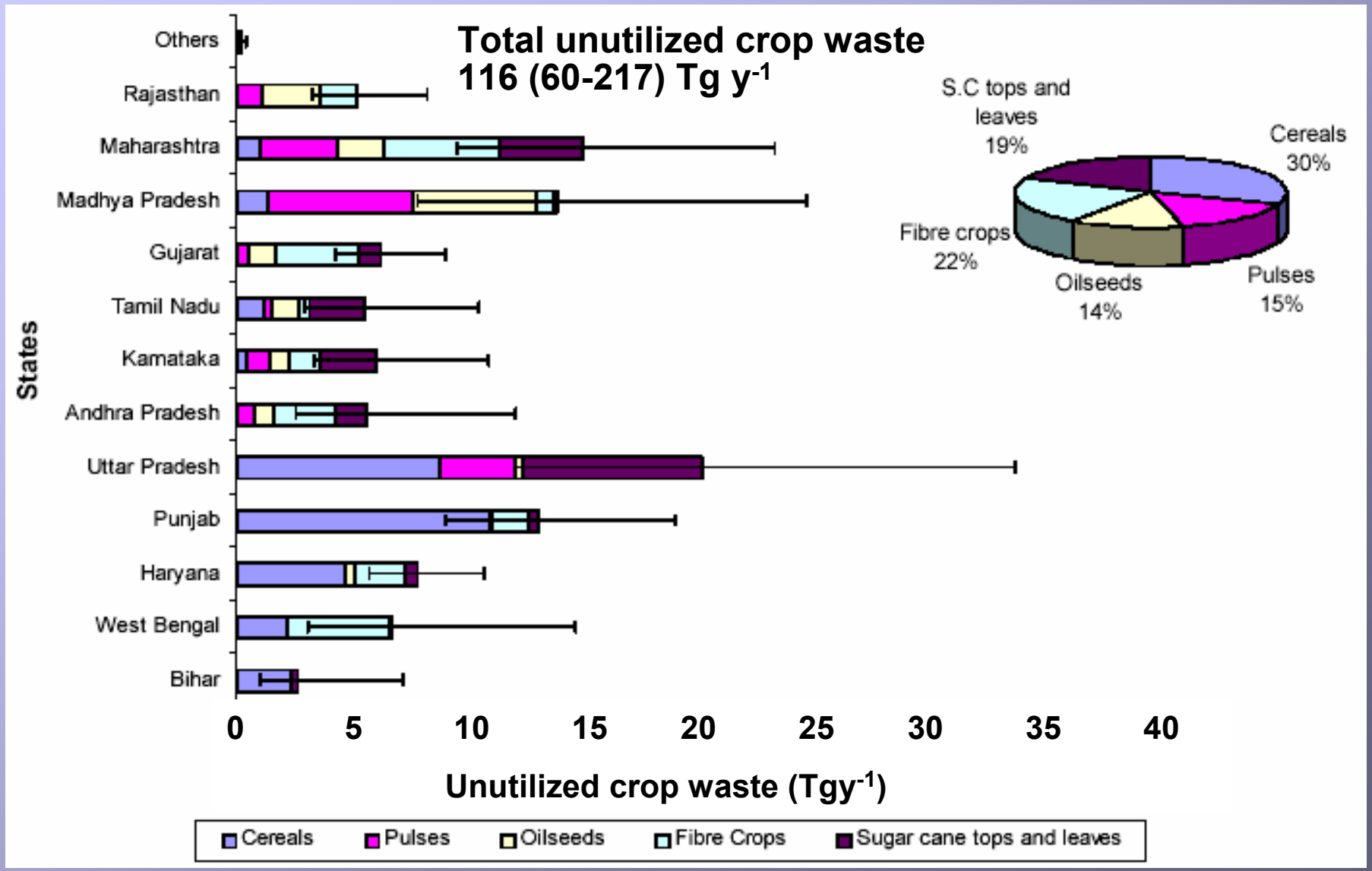


$$EM_{(i,\,j,\,month)} = \frac{EM_{(i,\,j)} \times MODIS\_ffr_{(ii,\,jj,\,month)}}{\sum_{month=1}^{month=12} MODIS\_ffr_{(ii,\,jj,\,month)}}$$

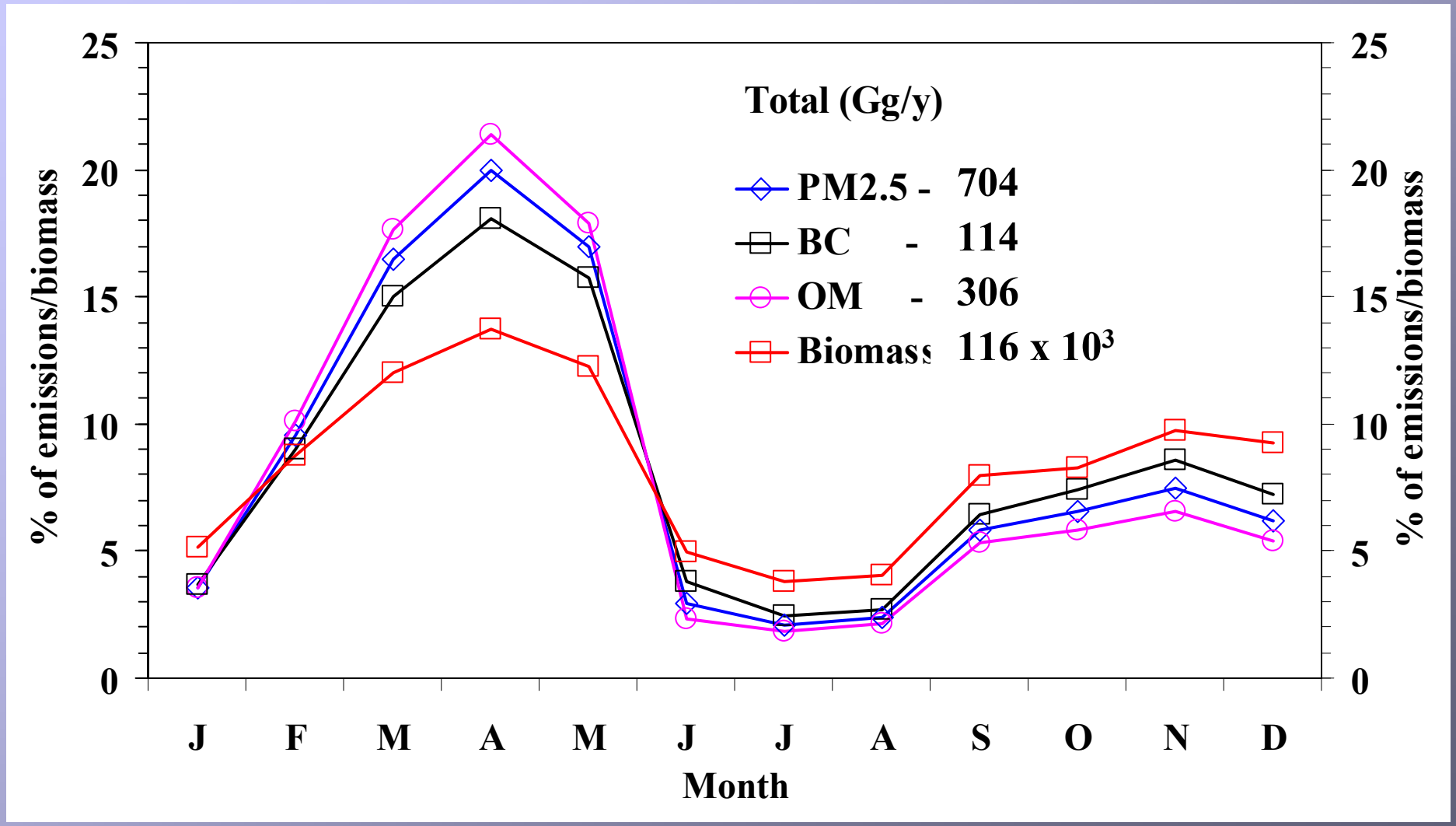
OPEN BURNING: AG WASTE MASS BALANCE



OPEN BURNING: UNUTILIZED AG WASTE

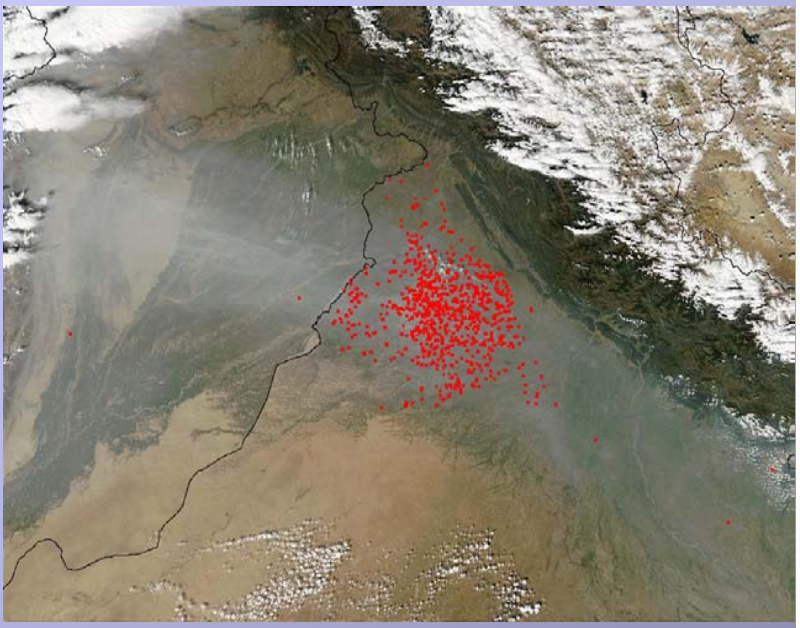


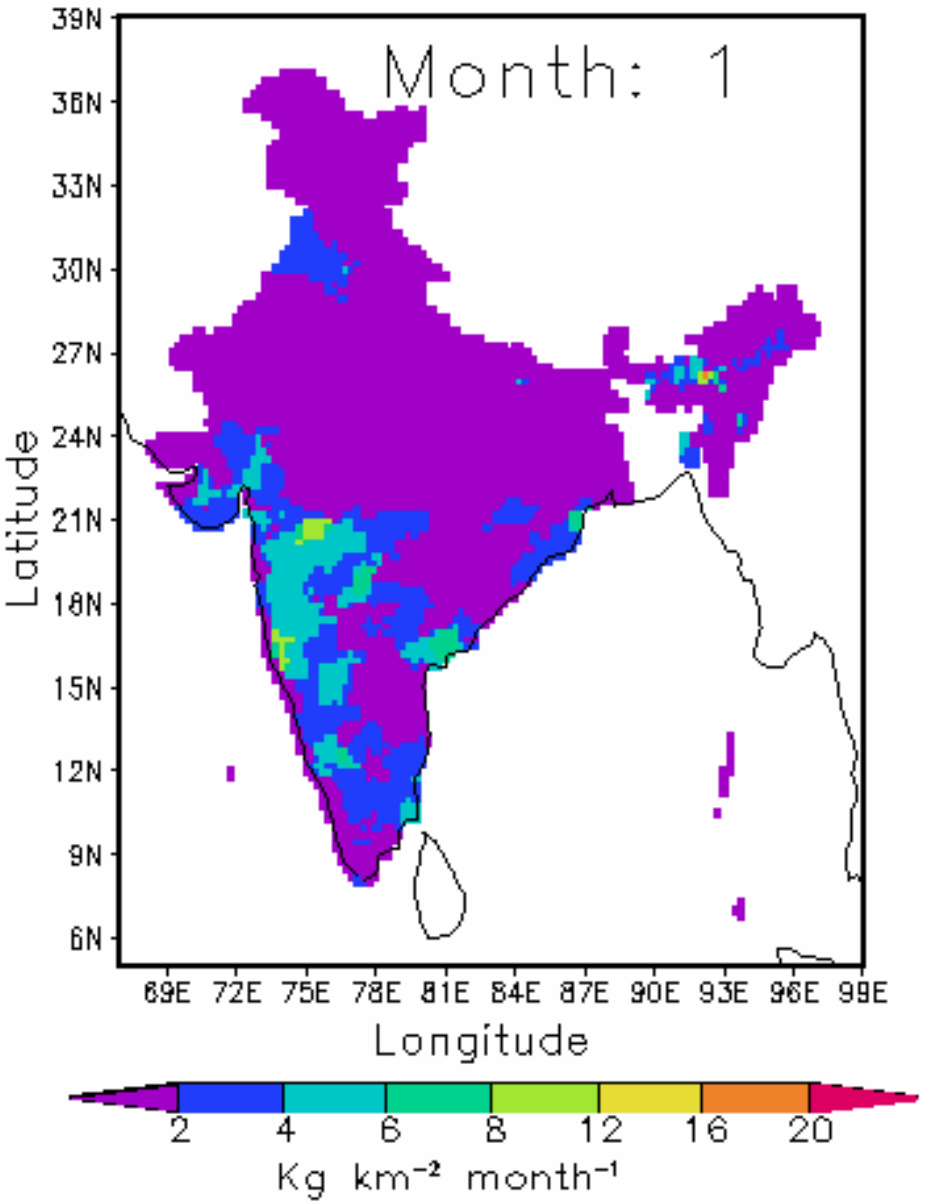
AG WASTE: SEASONAL EMISSIONS



AG WASTE: SPATIAL-TEMPORAL VARIABILITY

MODIS fire map: Oct 10, 2002





INDIA BC EMISSIONS SUMMARY (Gg y^{-1})

	This work	Mayol-Bracero et al., 2002	Dickerson et al., 2002	Reddy and Venkataraman, 2002; Reddy et al., 2002	Streets et al., 2003	Bond et al., 2004
Base year	**2000**	**2000-01**	**2000-2001**	**1999-00**	**2000**	**1996**
Total all sources	**426 (156-1365)[a] *(200%)***		**503**	**414**	**600**	**597 [671]**
Biofuel:	**174 (86-360) *(100%)*[b]**	**399**	**420**	**167**	**420 *(350%)***	**330 [351][d]**
OpenBrn: crop wst	**114 (45-295) *(160%)***	**-**	**29[c]**	**147**	**87 *(700%)***	**87**
Forest	**38 (5-305) *(700%)***					
Fossil fuel:		**65**	**54**	**90 (20-405) *(350%)***	**97 *(350%)***	**233**

[A]mean and range; [b]uncertainty at 95% CI; [c]only for forest fire; [d]Upgraded for current base year using rural population as proxy.

Simulations of the INDOEX "intensive field phase" in the LMDZ-GCM

Introduction of multi-component aerosols: sulphate, black carbon, organic matter, fly-ash, dust (<1µm; 1-10µm) and sea-salt (8 size bins).

India emissions at 0.25°x0.25° with ground level and elevated sources (MSR/CV 2002a, b). Asia emissions (Streets et al. 2003).

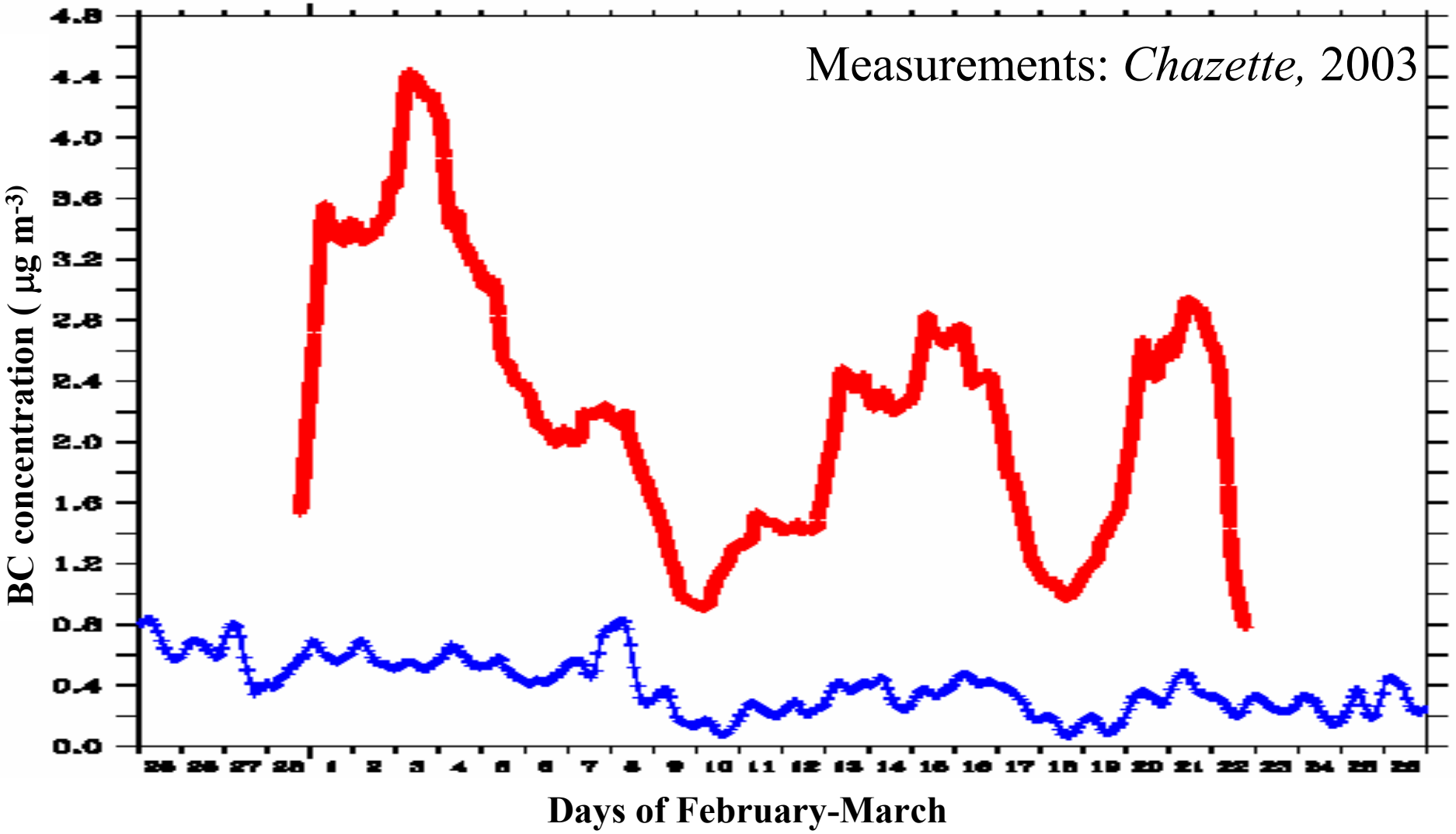
Seasonal/inter-annual BC emissions from biomass open burning distributed using ATSR fire counts.

Nudged to ECMWF winds from Nov 1998 to March 1999.

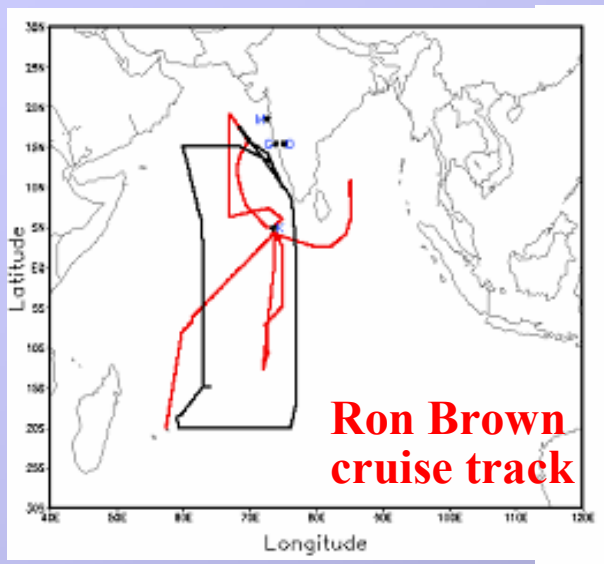
Parameterisation for carbonaceous aerosol growth from hydrophobic to hydrophilic state.

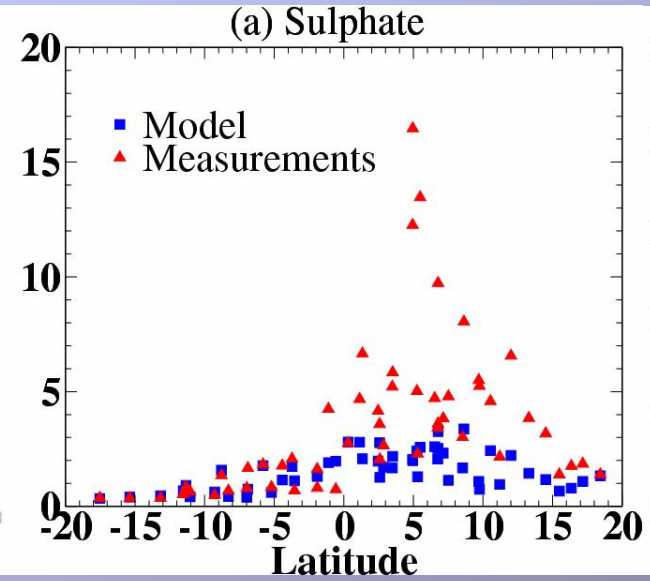
Wavelength depended aerosol optical properties at different relative humidity.

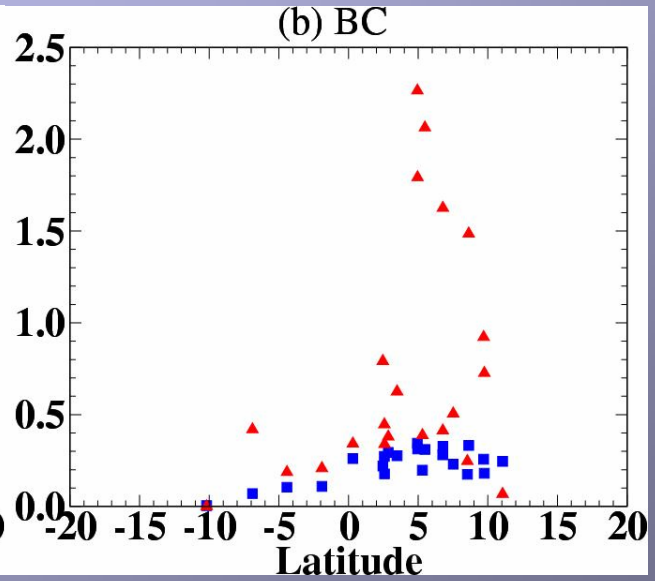
Evaluation with measurements: Surface concentrations at Goa (15.5N, 73.8E)

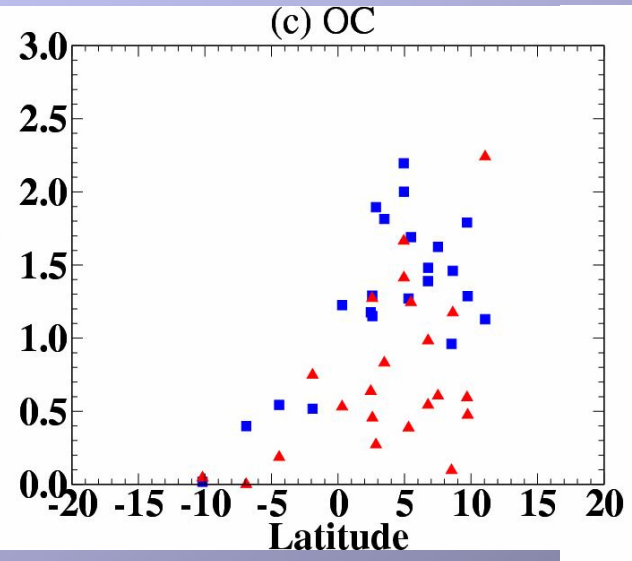


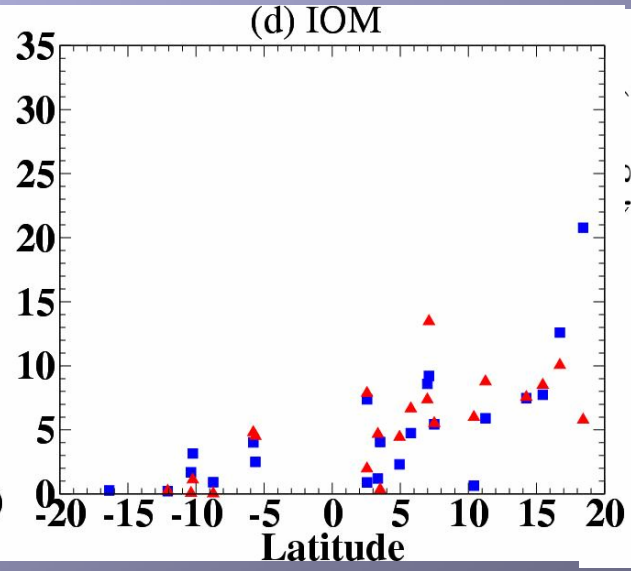
Evaluation with measurements: Surface concentrations over ocean (Ron Brown)

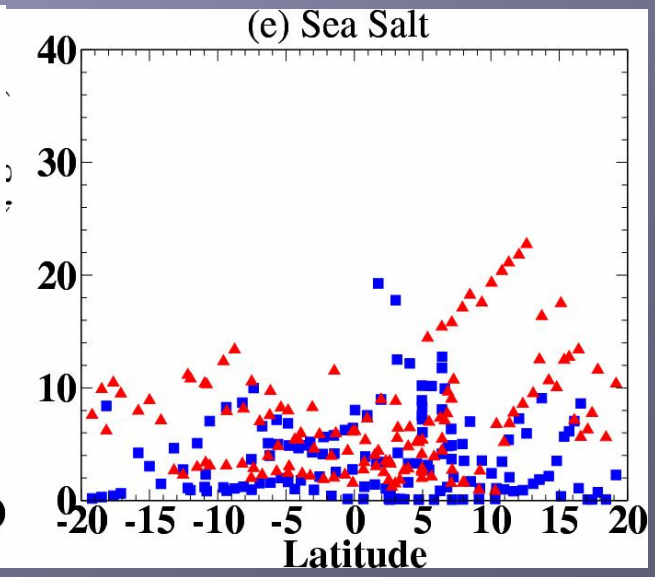




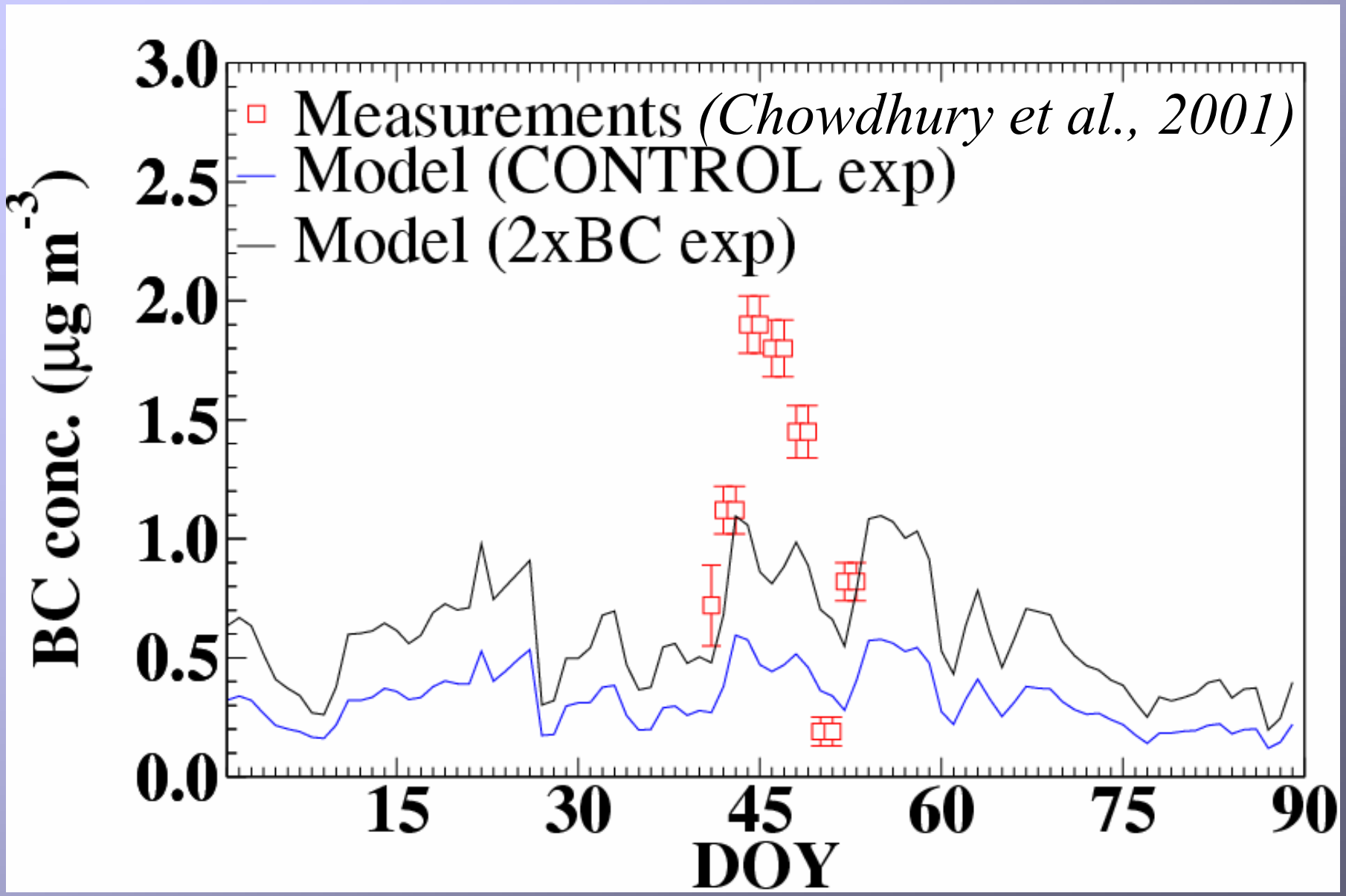




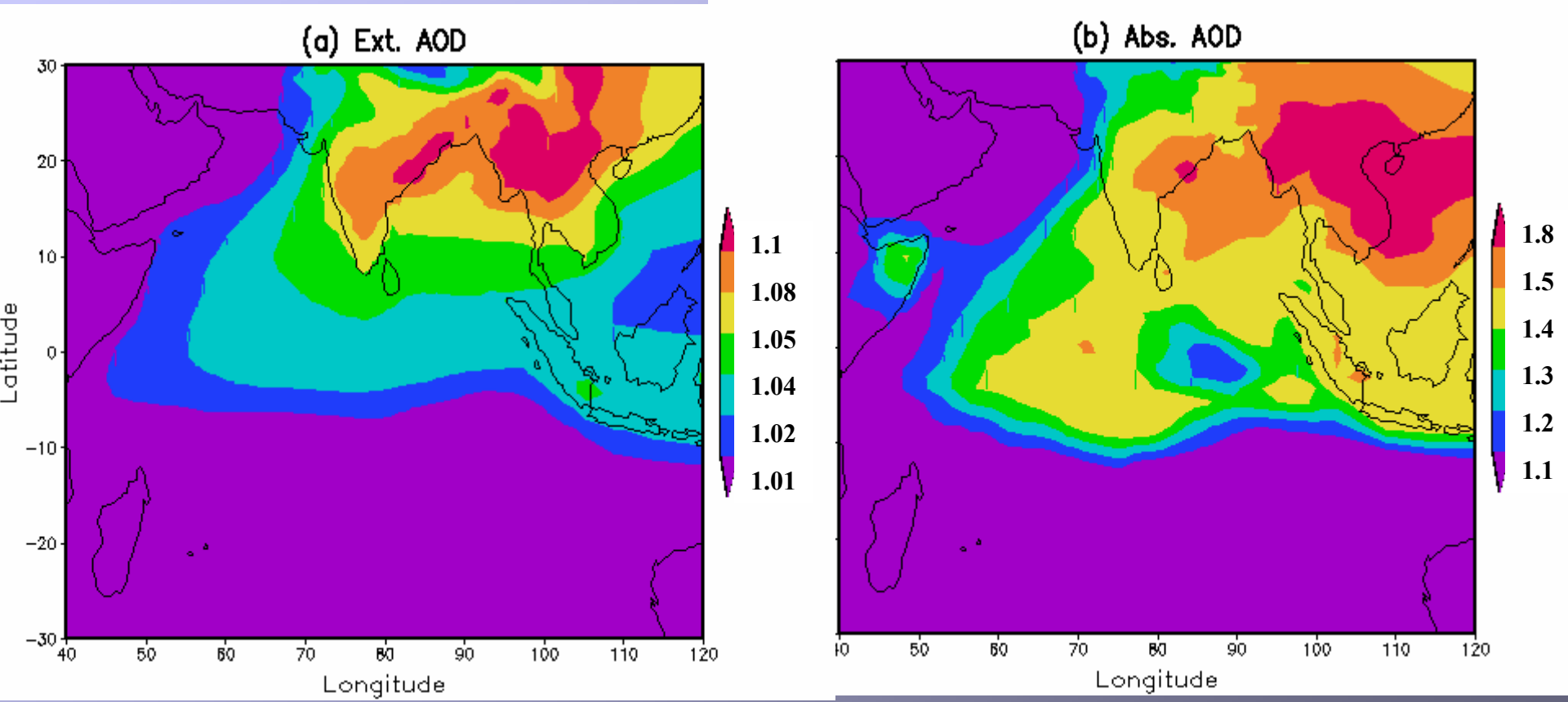




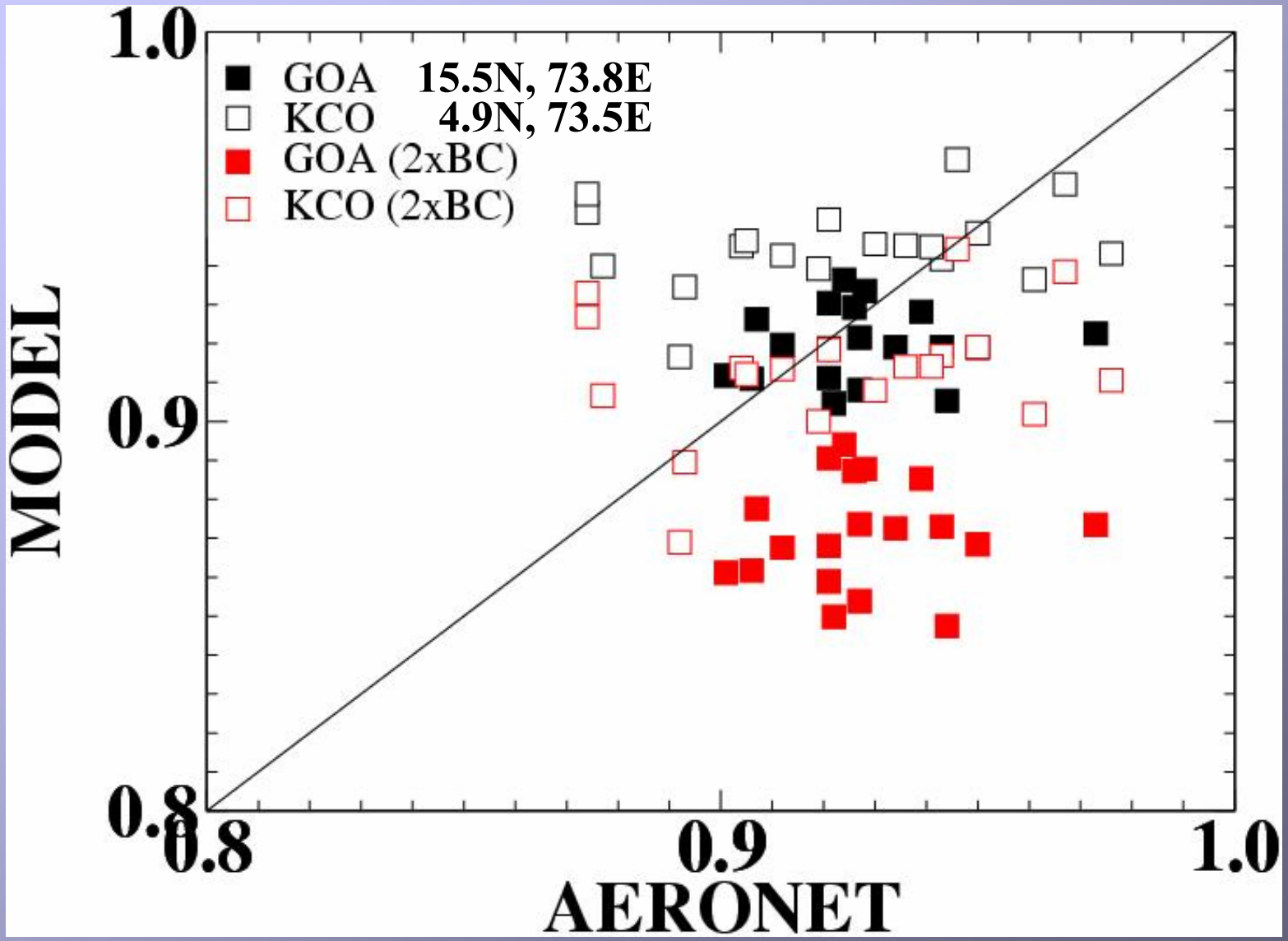
Sensitivity to Asian BC emissions: Surface concentrations at KCO 4.9N, 73.5E



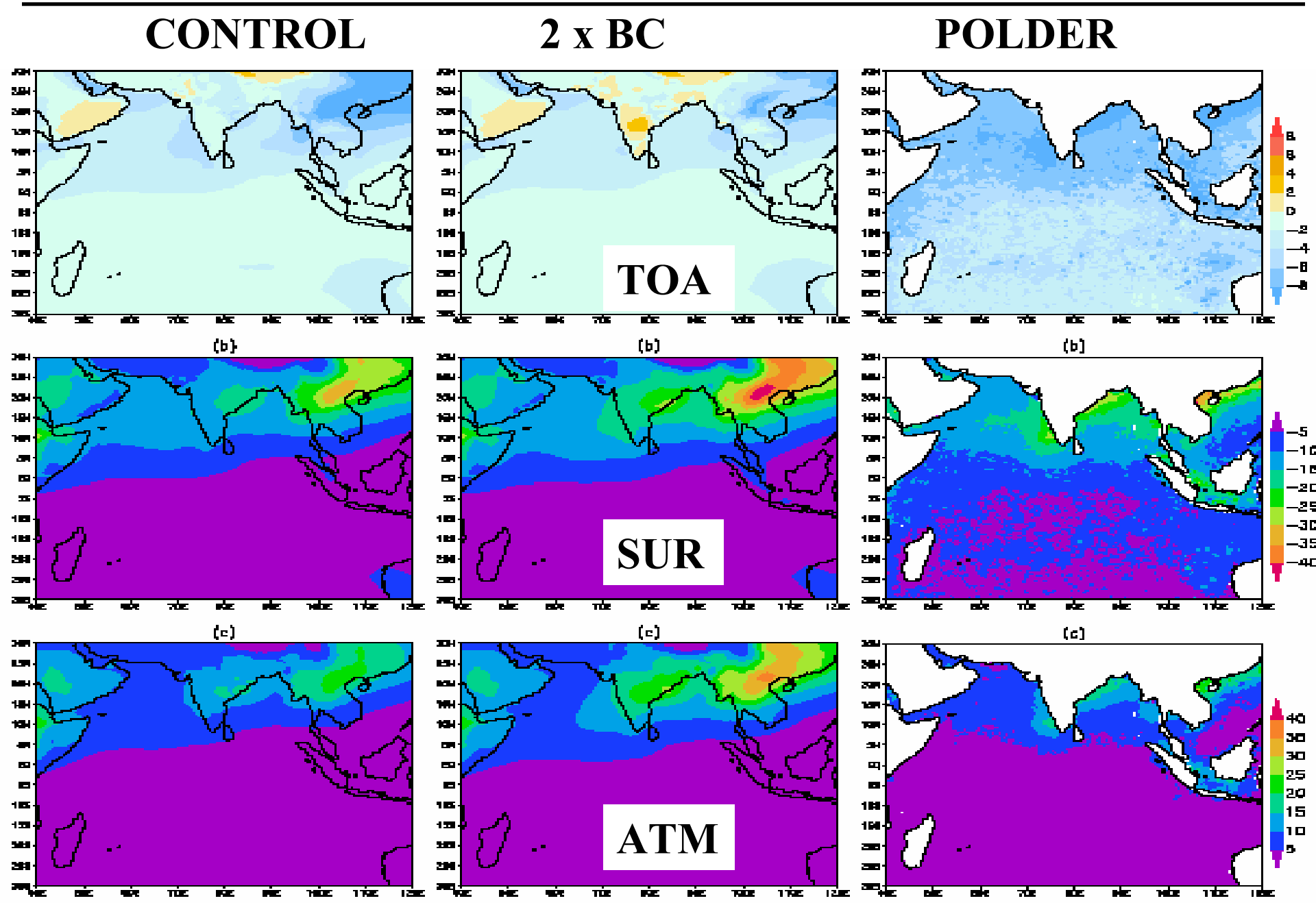
Sensitivity to Asian BC emissions: AOD



Sensitivity to Asian BC emissions: SSA



Sensitivity to Asian BC emissions: Radiative forcing



SUMMARY / NEEDS

- Uncertainties in S. Asian BC emissions can be constrained within factor of 2 (or 100%).

  - emission factors ~ vehicle classes (on-road emissions), industrial plants, brick kilns, etc.

  - open burning amounts and seasonal / interannual variability.

  - missing sources ~ agro-industries e.g. spice / tea drying, small-scale industries - restaurants/ confectioners, glass and bangle making, crematoriums.

- Present model estimates show systematic under-prediction.

  - restricted to winter monsoon – check seasonal / interannual variability.

  - wind data that drive model.

  - assimilate satellite derived AOD.

- Ambient measurements.

  - network of aethalometer measured “BC” being set up.

  - need ambient measurements.

RELATED PAPERS

- M.S. Reddy and C. Venkataraman **(2002)**. Inventory of Aerosol and Sulphur Dioxide Emissions from India: I – Fossil Fuel Combustion, *Atmospheric Environment*, **36 (4)**, 677-697.
- M.S. Reddy and C. Venkataraman **(2002)**. Inventory of Aerosol and Sulphur Dioxide Emissions from India: II – Biomass Combustion, *Atmospheric Environment*, **36 (4)**, 699-712.
- G. Habib, C. Venkataraman, M. Shrivastava, R. Banerji, J. Stehr and R. Dickerson **(2004)**. New methodology for estimating biofuel consumption for cooking: Atmospheric emissions of black carbon and sulfur dioxide from India, *Global Biogeochemical Cycles*, **18, GB3007,** doi:10.1029/2003GB002157.
- M.S. Reddy, O. Boucher, C. Venkataraman, S. Verma, N. Bellouin and M. Pham **(2004)**. GCM estimates of aerosol transport and radiative forcing during INDOEX, *Journal of Geophysical Research*, **109, D16205**, doi:10.1029/2004JD004557.
- C. Venkataraman, G. Habib, A. Eiguren-Fernandez, A.H. Miguel and S.K. Friedlander **(2004)**. Carbonaceous aerosol emissions from residential biofuel combustion in S. Asia and climate implications, submitted.
- G. Habib, C. Venkataraman, T.C. Bond and J.J. Schauer, A. Eiguren-Fernandez, A.H. Miguel, S.K. Friedlander **(2004)**. Primary particle emissions biofuel combustion: Chemical composition, size distribution and optical properties, in preparation.