Assembling Emission Inventories of Primary Carbonaceous Aerosols

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Recent work by Hansen, Jacobson, and others suggests that BC is a very important greenhouse species

Net forcing = 1.6 +/- 1.1 W/m^2

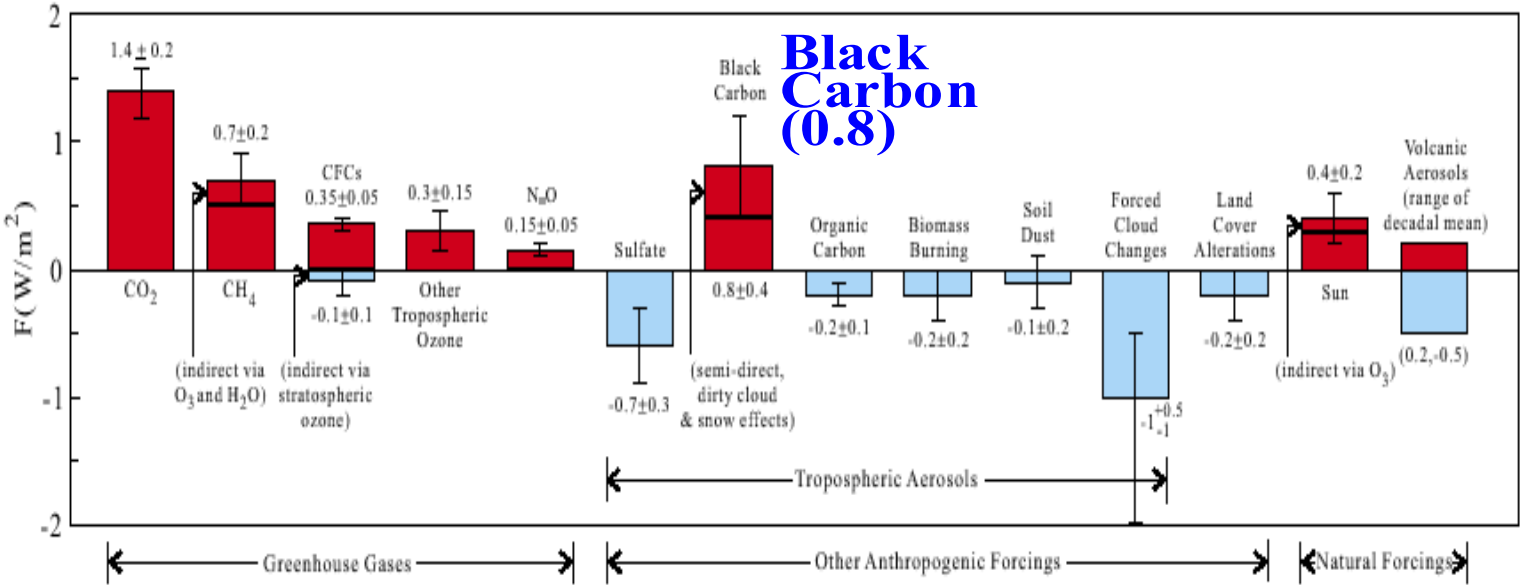


Figure 2. Estimated change of climate forcings between 1850 and 2000.

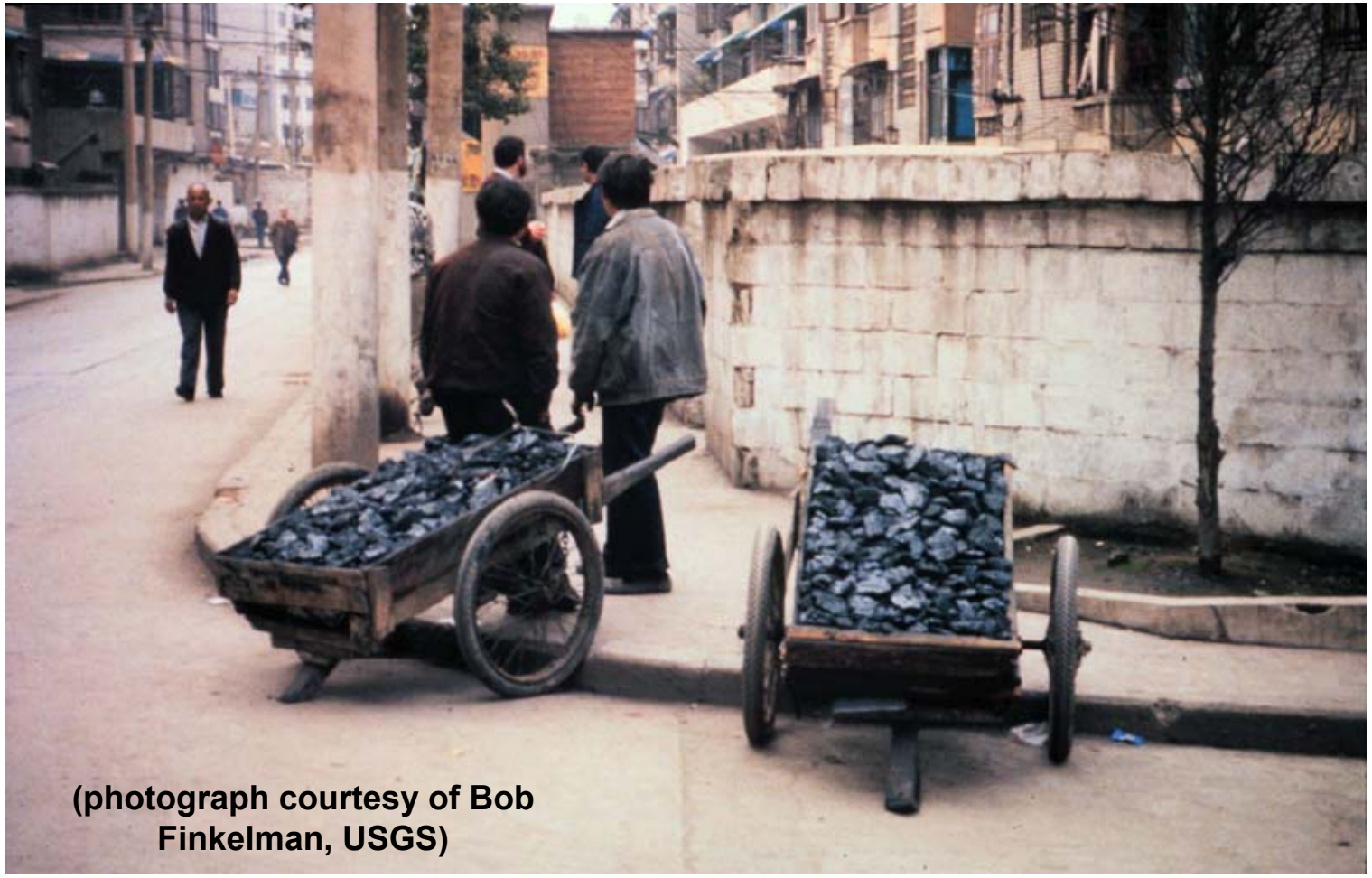
(Hansen et al., Senate testimony, May 1, 2001; Hansen and Sato, PNAS)

James Hansen's "Alternative" Scenario (released August 29, 2000)

"Our analysis of climate forcings suggests, as a strategy to slow global warming, an alternative scenario focused on reducing non-CO_2 GHGs and black carbon (soot) aerosols.... (R)eductions in tropospheric ozone and black carbon would not only improve local health and agricultural productivity but also benefit global climate and air quality."

J. Hansen, M. Sato, R. Ruedy, A. Lacis, and V. Oinas, Global warming in the twenty-first century: an alternative scenario, Proceedings of the National Academy of Sciences, 97, 9875-9880, 2000

The biggest source of BC is residential burning of coal and biofuels in developing countries (not power plants)



(photograph courtesy of Bob Finkelman, USGS)

There are problems with the BC and OC emission inventories* that are in common use by global modelers today

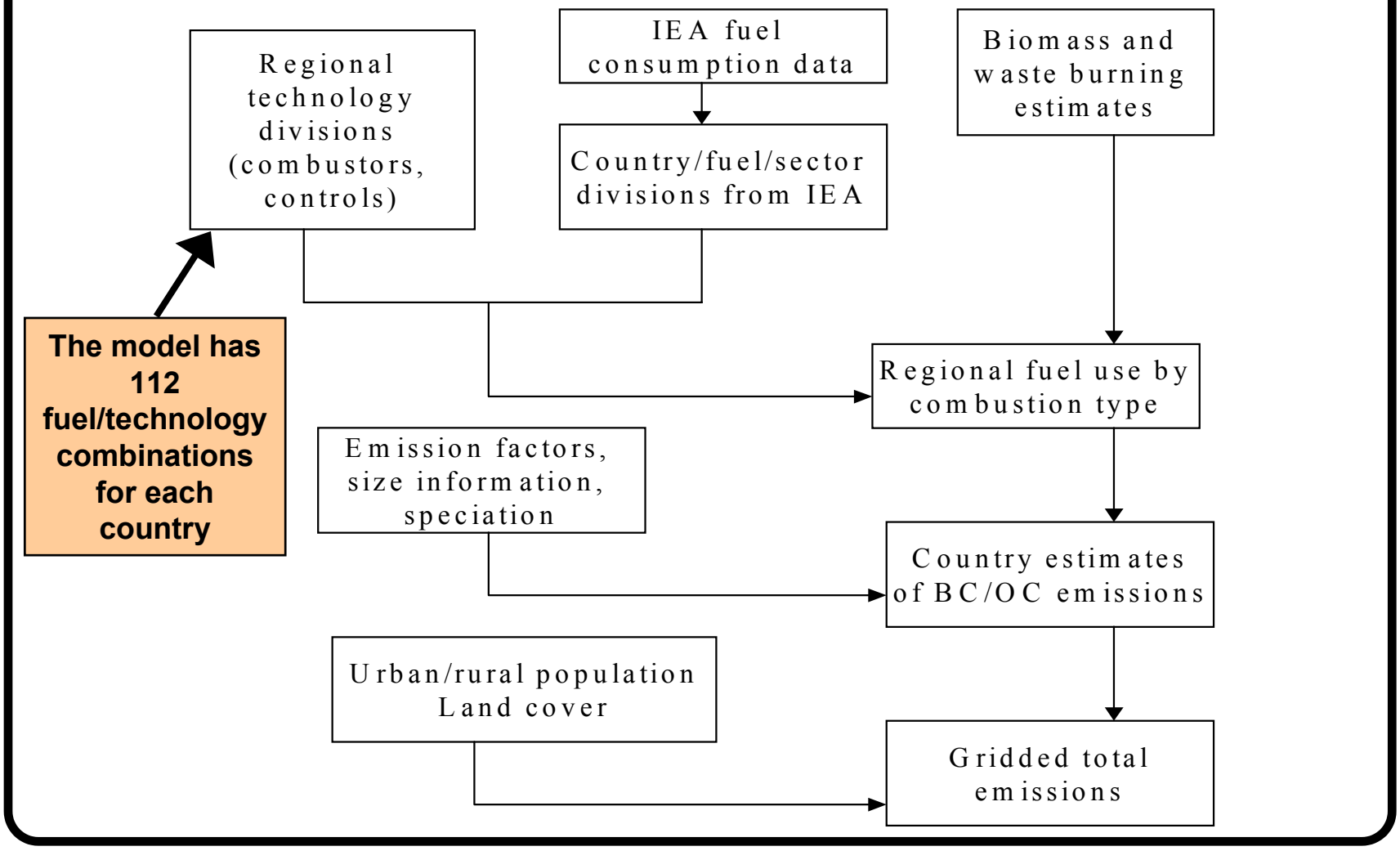
- they are based on old fuel use data (1984)
- they use inappropriate emission factors, especially for large coal combustors
- they do not consider technology variations in sufficient detail
- they do not treat biofuels carefully
- they do not treat residential stoves carefully

*Cooke and Wilson (fossil fuels only): JGR, 101, 19395-19409, 1996

Cooke et al. (fossil fuels only): JGR, 104, 22137-22162, 1999

Liousse et al. (biofuels and open biomass): JGR, 101, 19411-19432, 1996

Methodology for this new 1996 BC/OC Emission Inventory



Calculation of BC and OC emission factors (g kg^{-1} of fuel burned)

$$EF_{BC} = EF_{PM} \times F_{1.0} \times F_{BC} \times F_{cont}$$

$$EF_{OC} = EF_{PM} \times F_{1.0} \times F_{OC} \times F_{cont}$$

where:

EF_{PM} = bulk particulate emission factor (usually PM_{10})

$F_{1.0}$ = fraction of the emissions that are < 1 µm in diameter

F_{BC}, F_{OC} = fraction of the particulate matter that is carbon

F_{cont} = fraction of the fine PM that penetrates any control device that might be installed

Examples of EF_{PM} (g kg^{-1}) and fractions used to develop the BC and OC emission factors

Fuel/Technology	EF_{PM}	$F_{1.0}$	F_{BC}	F_{OC}	F_{cont}
Biofuel stove	10	0.85	0.1	0.6	1.0
Biofuel stoker	2.2	0.86	0.05	0.2	0.4-1.0
Briquettes	2.5	0.25	0.01	0.02	0.3-1.0
Brown coal stoker	17	0.11	0.05	0.66	0.06-1.0
Hard coal stoker	4.2	0.33	0.1	0.02	0.05-1.0
Hard coal PC	12	0.09	0.006	0	0.05-0.9
Heavy fuel oil	1.1	0.45	0.08	0.03	0.13-1.0
Kerosene stove	0.9	1.0	0.13	0.1	1.0
Natural gas	0.002	1.0	0.06	0.5	1.0
Solid waste open burn	30	0.5	0.37	0.37	1.0

Examples of calculated EF_{BC} (g kg^{-1}) for various fuels and sectors

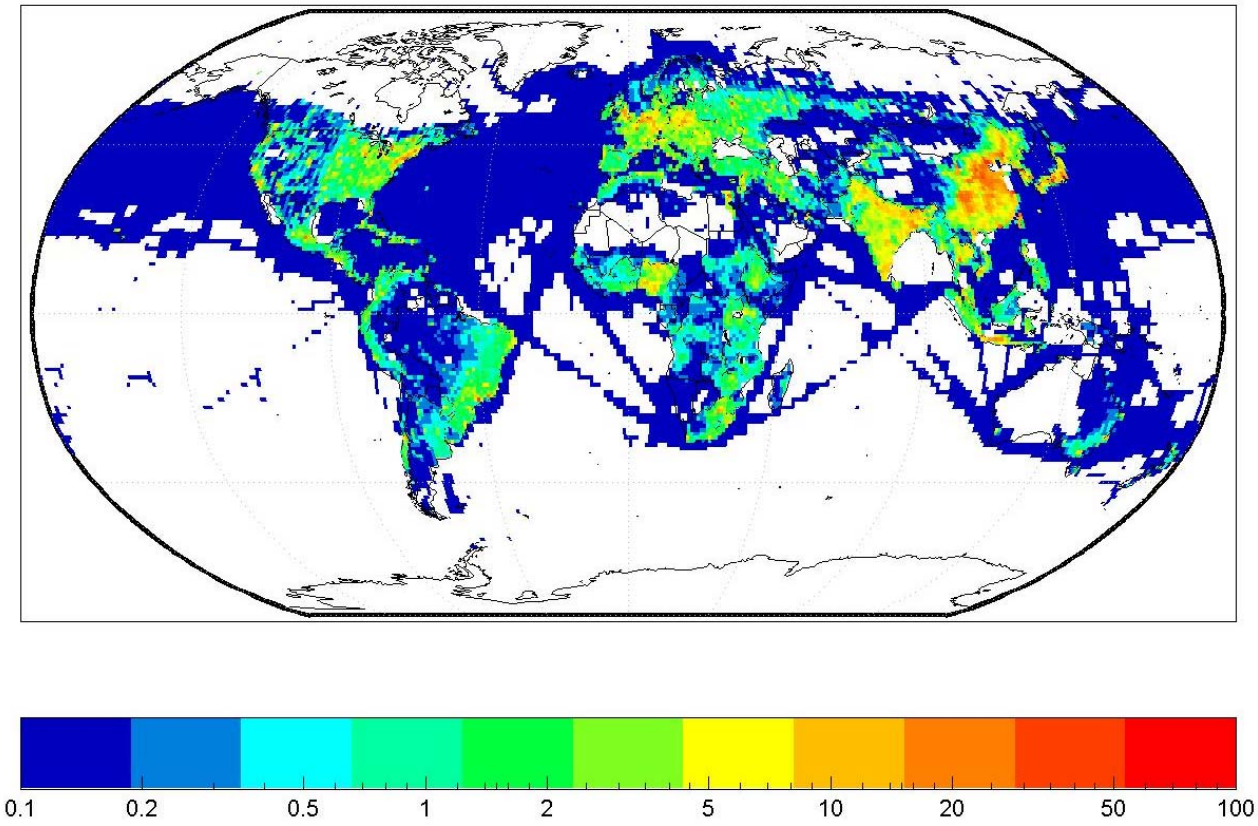
Fuel	Residential	Industry	Power	Transport
Wood	0.3-1.4	0.08-0.55	0.044	--
Ag waste	1.0	--	--	--
Briquettes	0.15	0.005	0.011	--
Brown coal	0.18	0.001-0.015	0-0.002	--
Hard coal	0.89-5.4	0.007-1.2	0.008-1.2	3.0
Diesel oil	0.06-4.0	3.4-4.4	0.25	1.3-3.6
Gasoline, etc.	0.9	0.14	--	0.08-0.43
Natural gas	0	0	0	0
Solid waste	4.2	0.013	0.013	--
Open biomass burning	0.48 (savanna)	0.69 (crop residues)	0.56-0.61 (forests)	

Emissions are gridded using total population distribution, except for the following cases that use other proxies:

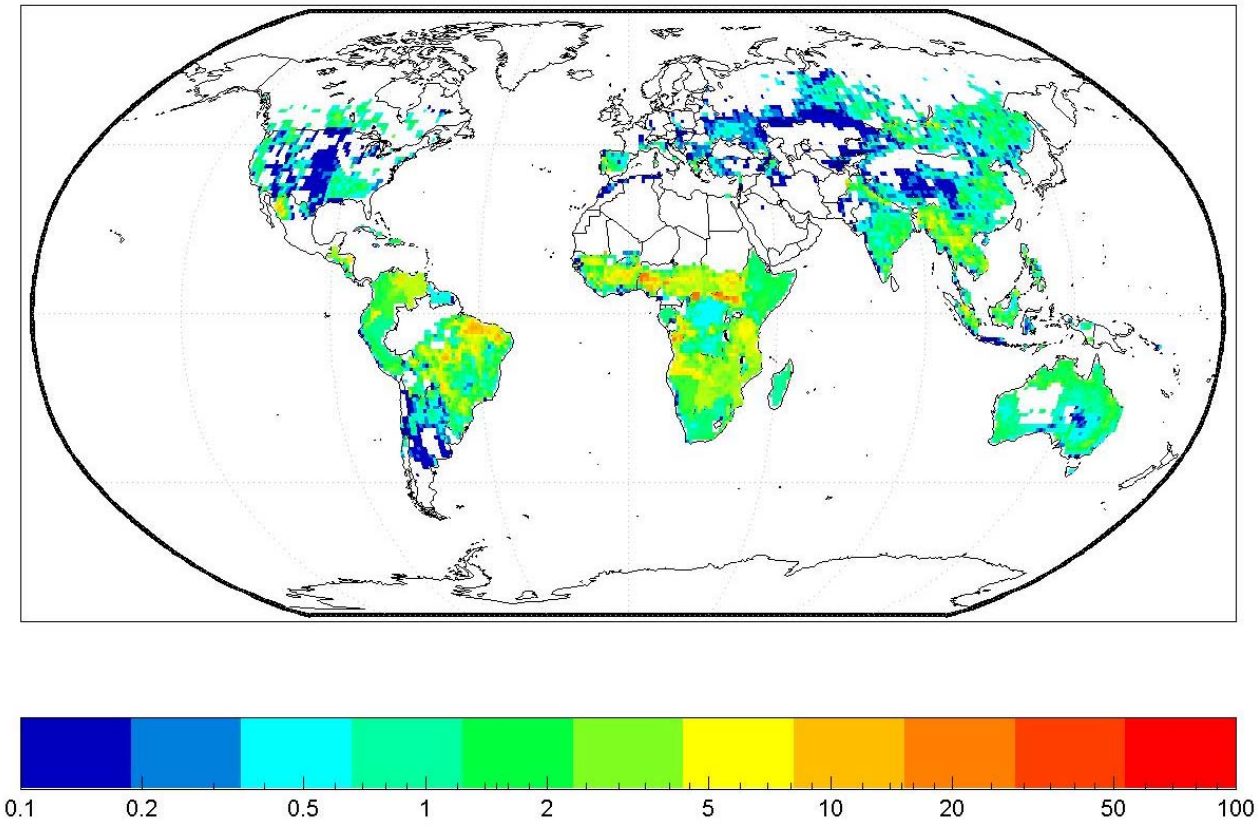
• Residential sector (fires/stoves)	rural population
• Open waste burning	urban population
• Agricultural diesel use	agricultural landcover
• International shipping	shipping lanes
• Forest burning	forest landcover*
• Savanna burning	savanna landcover*
• Ag waste burning	agricultural landcover*

*Adjusted by AVHRR fire counts for 1999-2000

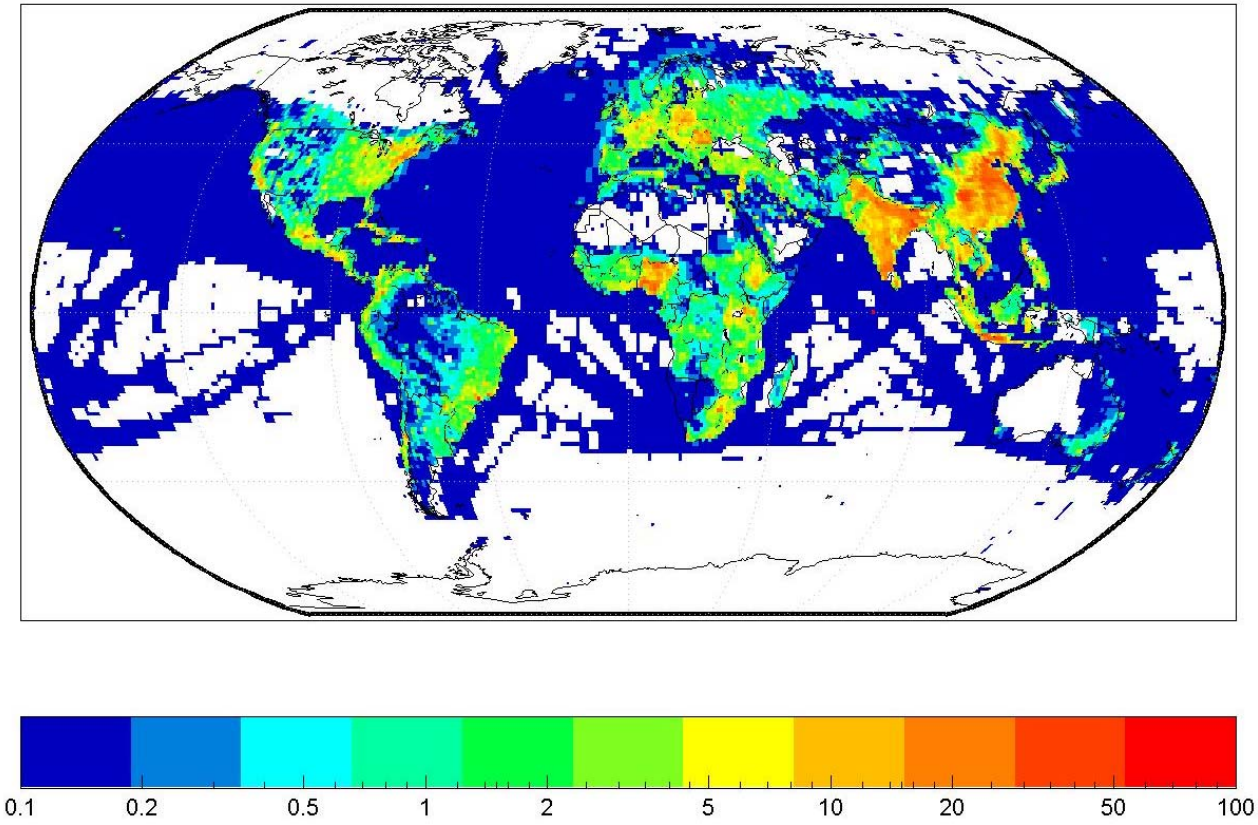
Global distribution of BC emissions from fuel combustion (ng m^{-2} sec^{-1})



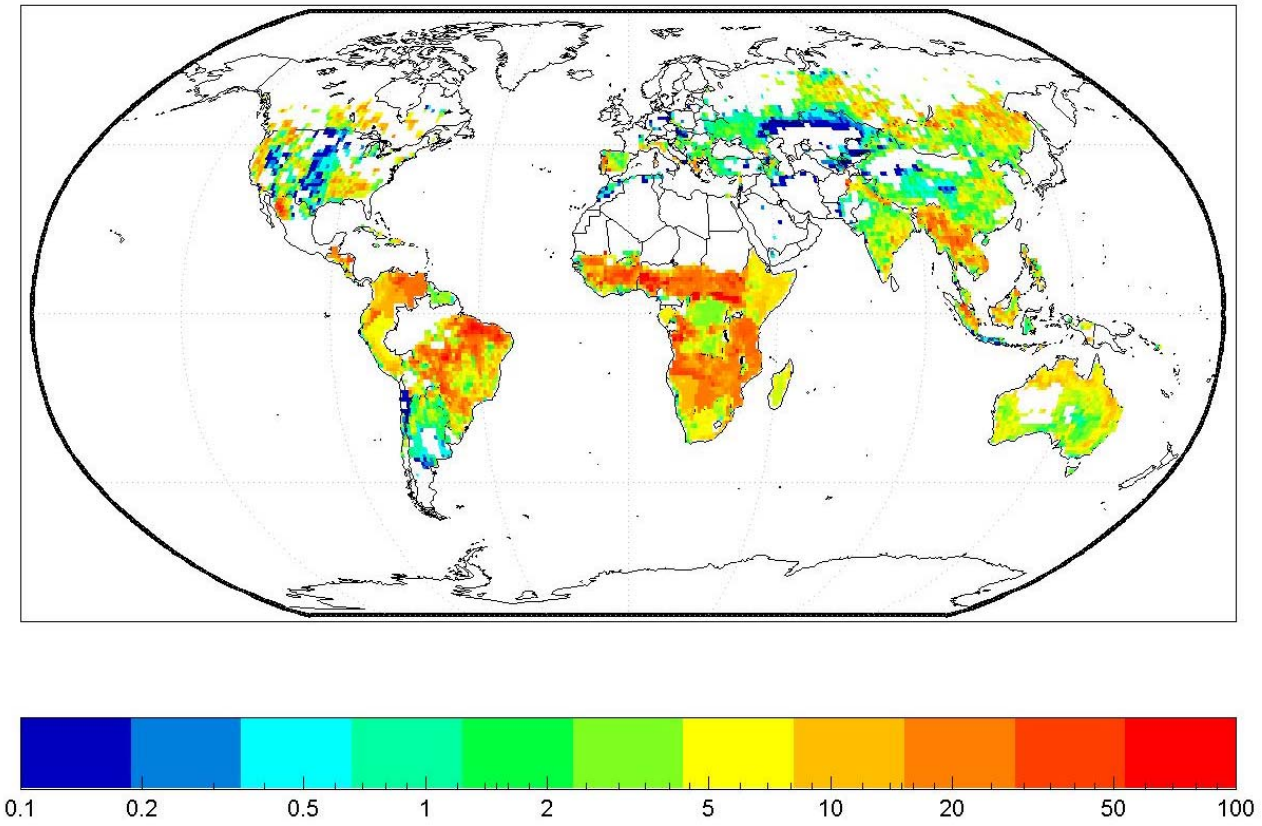
Global distribution of BC emissions from open biomass burning (ng m^{-2} sec^{-1})



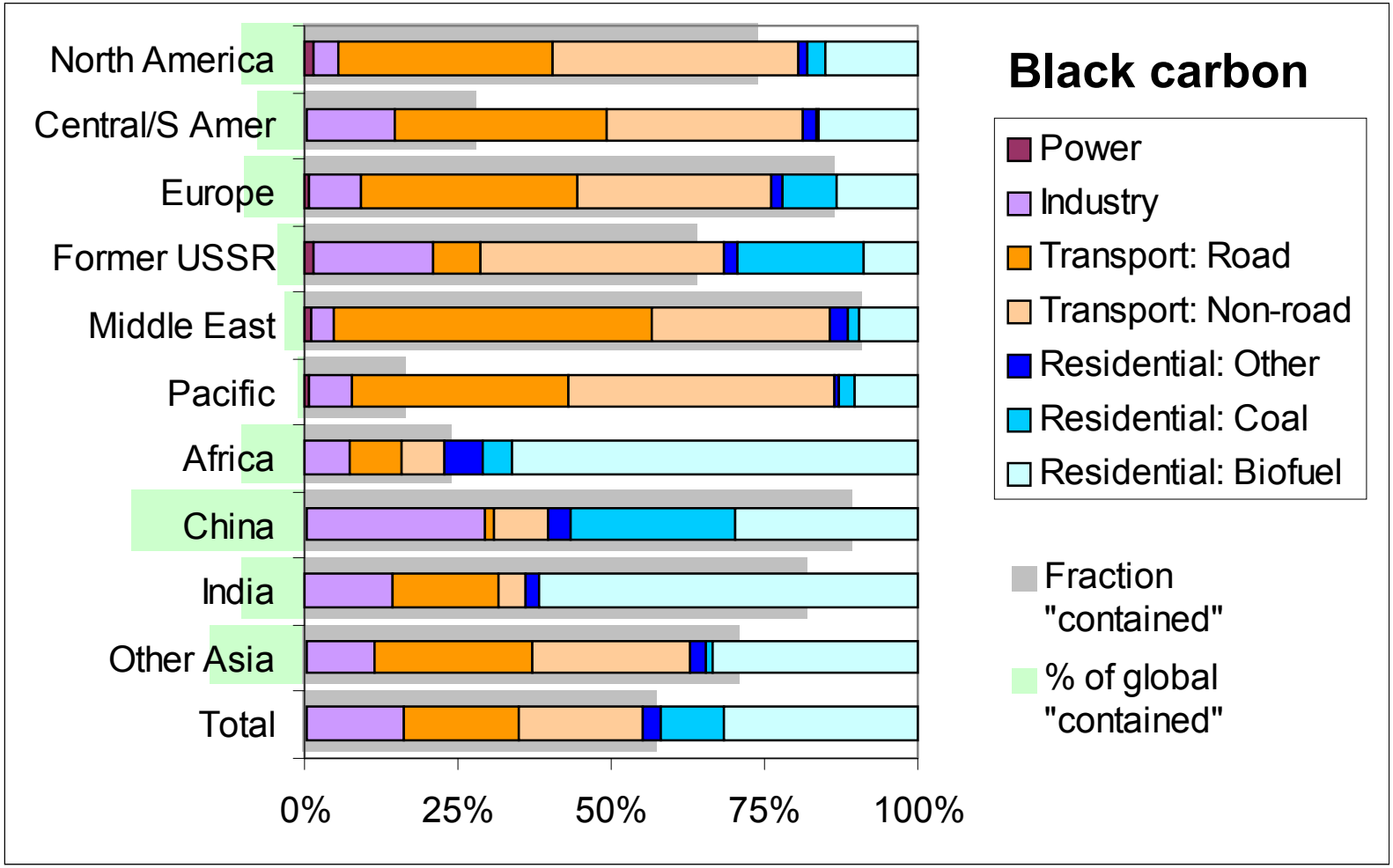
Global distribution of OC emissions from fuel combustion (ng m^{-2} sec^{-1})



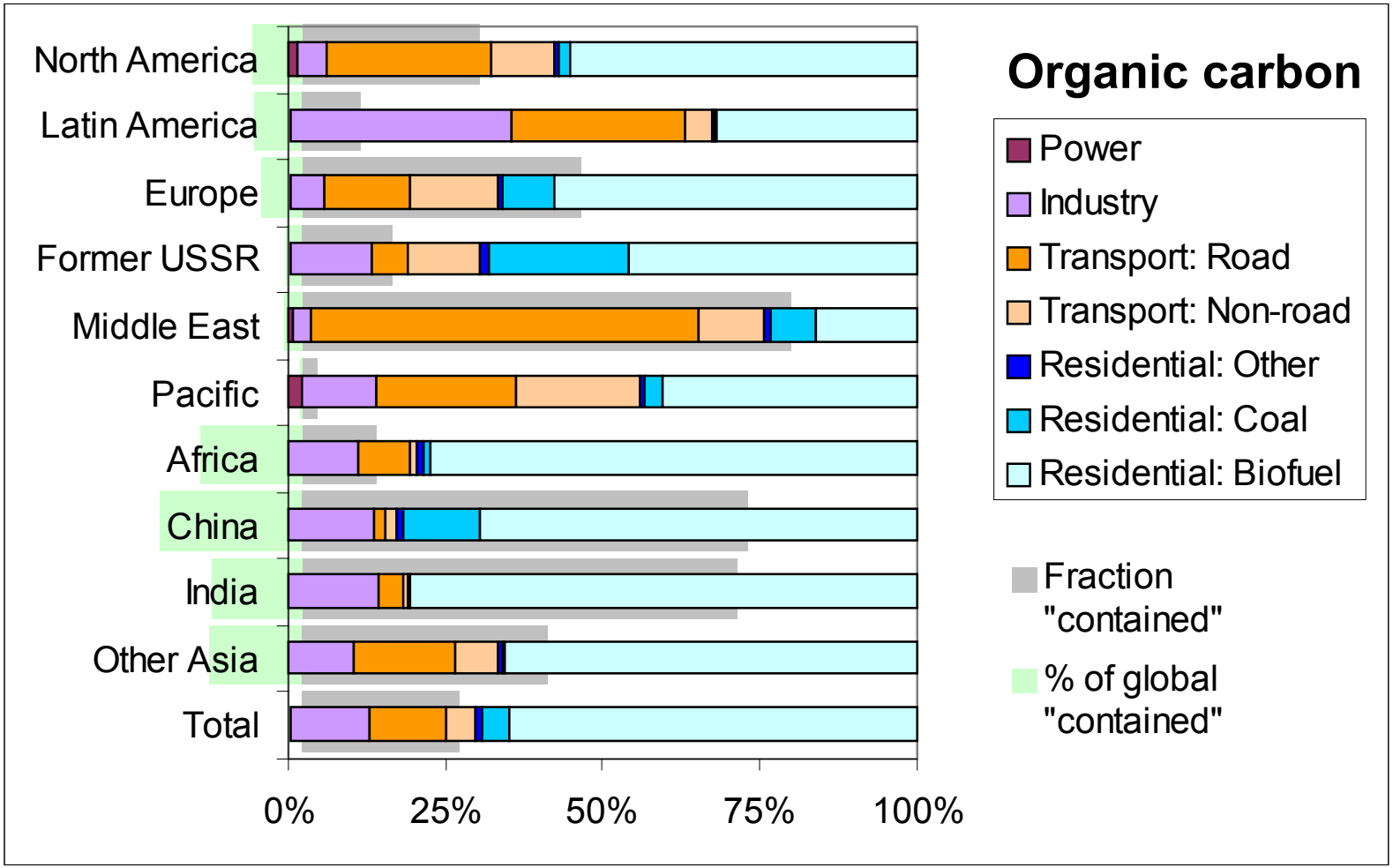
Global distribution of OC emissions from open biomass burning (ng m^{-2} sec^{-1})



Sector and region contributions to global BC emissions



Sector and region contributions to global OC emissions



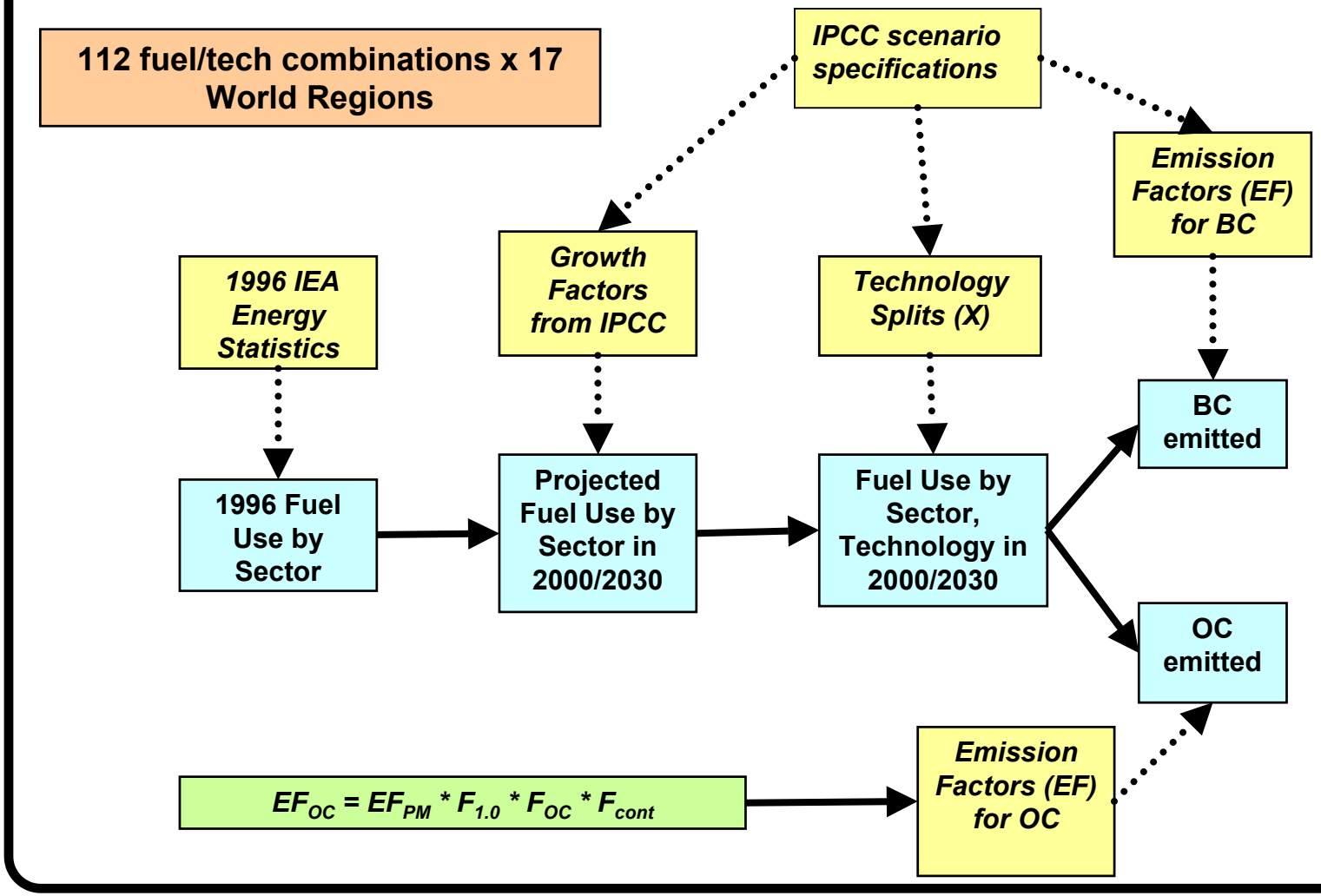
Comparison of BC emissions (Gg yr^{-1}) in this inventory with Cooke et al. (1999) & Liousse et al. (1996), as used in many global model studies

Fuel/Sector	This work	Previous84	Previous96
Coal/power generation	7	2840	1594
Coal/industrial	610		1181
Coal/residential	517		761
Diesel/on-road	907	1710	1917
Diesel/residential	98		369
Diesel/off-road	682		696
Gasoline/transport	108		41
Wood/residential	877	1000	1921
Dung/residential	208		417
Ag waste/residential	393		90
Open burning/crop residues	327	530	356
Open burning/savanna	1726	2170	2912
Open burning/forests	1244	1930	2980
Other	354		447
Total	8058	10700	15682

Reasons for major differences between this inventory and previous work (Cooke et al., 1999; Liousse et al., 1996)

Fuel/Sector	ΔPrev96	Reason
Coal/Power generation	~1500 Gg	PM was assumed to be 25% BC, 25% OC. No measurements support this assertion. PM is mostly mineral matter.
Diesel/Residential	~250 Gg	Engine emission factors were applied to residential use of diesel. These are not appropriate for home furnaces.
Diesel/On-road	~1000 Gg	BC emission factor assumed to be 10 g/kg in developing countries. *No measurements* support this value – even studies targeting polluting vehicles in developing countries.
Wood/residential	~1000 Gg	PM emission factors from fireplace combustion were used for cooking stoves. Measurements show that cookstove emission factors are much lower.
Open biomass burning	~3000 Gg	New emission factors from Andreae and Merlet (2001)

We are developing a capability to develop emissions for past and future years, initially 2000 and 2030, later, maybe, 1850-2100 (!?)

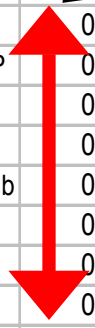


The BC/OC regional model begins by importing energy use from international statistics or global energy forecasts (Gg fuel)

Master Code	Sector / Fuel Type	Canada	USA	Central America	South America	Northern Africa	Western Africa	Eastern Africa	Southern Africa
	Power	**77382**	**1698040**	**260979**	**198110**	**156495**	**27368**	**4682**	**353502**
68	Biofuel	2132	72240	14415	28573	0	0	0	0
76	Briquettes	212	990	0	497	0	0	0	0
83	Brown Coal	16110	120672	0	0	0	0	0	0
51	Coking Coal	0	0	0	0	0	0	0	0
57	Diesel Fuel	309	4023	11793	12303	15619	6675	2784	437
63	Hard Coal	53210	1211426	56738	54449	16810	6768	0	351266
50	Heavy Fuel Oil	1819	118773	155555	38284	61612	6317	1898	1140
47	Natural Gas	3589	128786	22478	64003	62454	7608	0	658
65	Waste, Municipal	0	41130	0	0	0	0	0	0

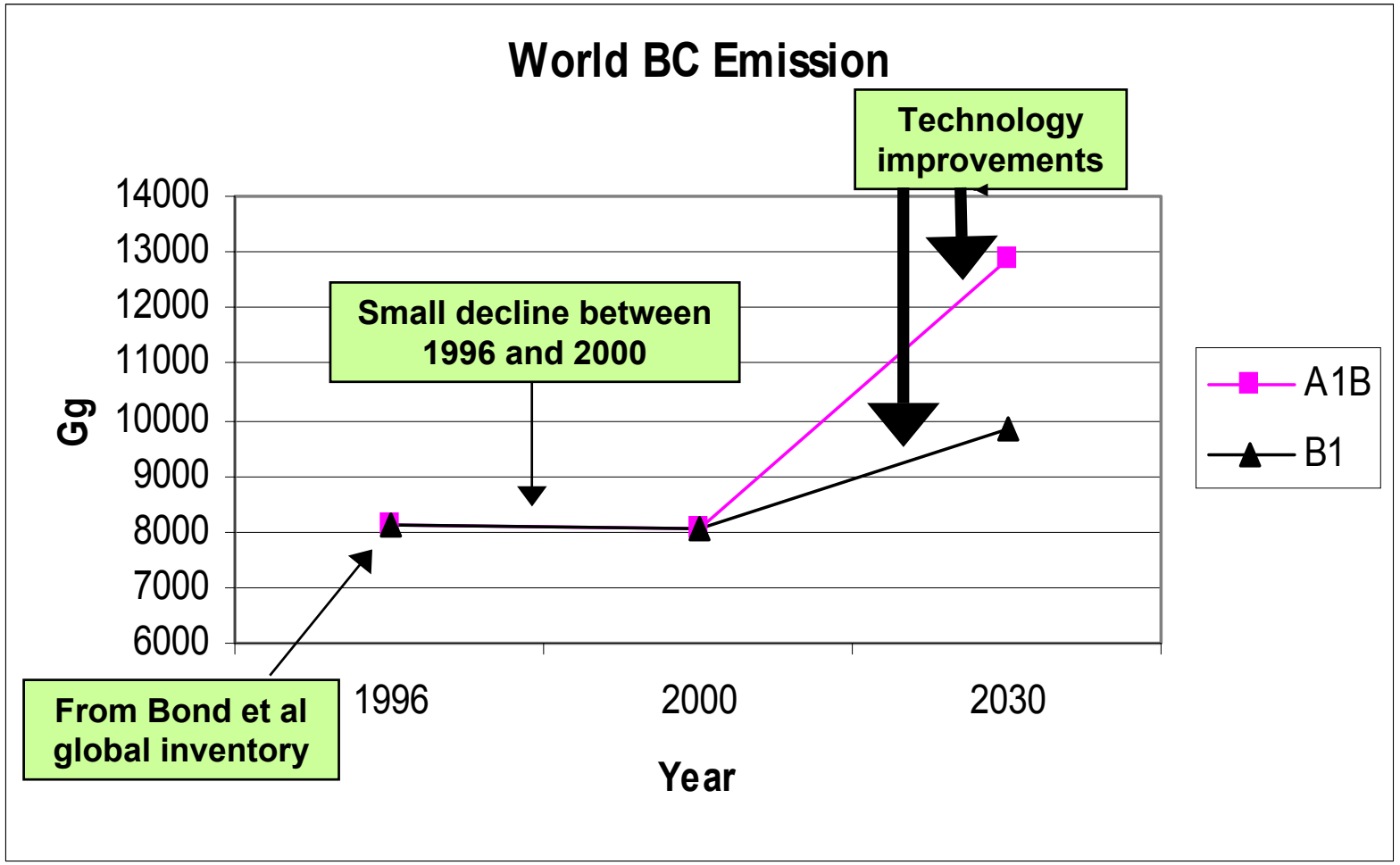
Technology splits reflect scenario, regional, and technology differences

Tech Code	Fuel1	Combustor/Control	Canada	USA	Central America	South America	Northern Africa	Western Africa	Eastern Africa	Southern Africa
	Power									
68	Biofuel	General	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
117	Briquettes	Stoker/Cyclone	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
41	Brown Coal	Pulverized Coal/Cycl	0.000	0.000	0.200	0.200	0.200	0.200	0.200	0.200
39	Brown Coal	Pulverized Coal/ESP	0.995	0.995	0.600	0.600	0.600	0.600	0.600	0.600
40	Brown Coal	Pulverized Coal/Scrub	0.000	0.000	0.150	0.150	0.150	0.150	0.150	0.150
72	Brown Coal	Stoker/Cyclone	0.005	0.005	0.030	0.030	0.030	0.030	0.030	0.030
119	Brown Coal	Stoker/ESP or Filter	0.000					0.000	0.000	0.000
71	Brown Coal	Stoker/Scrubber	0.000					0.020	0.020	0.020
51	Coking Coal	General	1.000					1.000	1.000	1.000
66	Coking Coal	Stoker/Scrubber	1.000					1.000	1.000	1.000
57	Diesel Fuel	General	1.000					1.000	1.000	1.000
112	Hard Coal	Cyclone/Cyclone	0.000					0.050	0.050	0.050
110	Hard Coal	Cyclone/Filter or ESP	0.000	0.000	0.050	0.050	0.050	0.050	0.050	0.050
22	Hard Coal	Pulverized Coal/Cycl	0.000	0.000	0.100	0.100	0.100	0.100	0.100	0.100
20	Hard Coal	Pulverized Coal/ESP	0.960	0.960	0.500	0.500	0.500	0.500	0.500	0.500
21	Hard Coal	Pulverized Coal/Scrub	0.000	0.000	0.250	0.250	0.250	0.250	0.250	0.250
69	Hard Coal	Stoker/Cyclone	0.020	0.020	0.030	0.030	0.030	0.030	0.030	0.030
19	Hard Coal	Stoker/ESP or Filter	0.020	0.020	0.000	0.000	0.000	0.000	0.000	0.000
70	Hard Coal	Stoker/Scrubber	0.000	0.000	0.020	0.020	0.020	0.020	0.020	0.020
50	Heavy Fuel Oil	General	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
47	Natural Gas	General	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
65	Waste, Municipal	General	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000



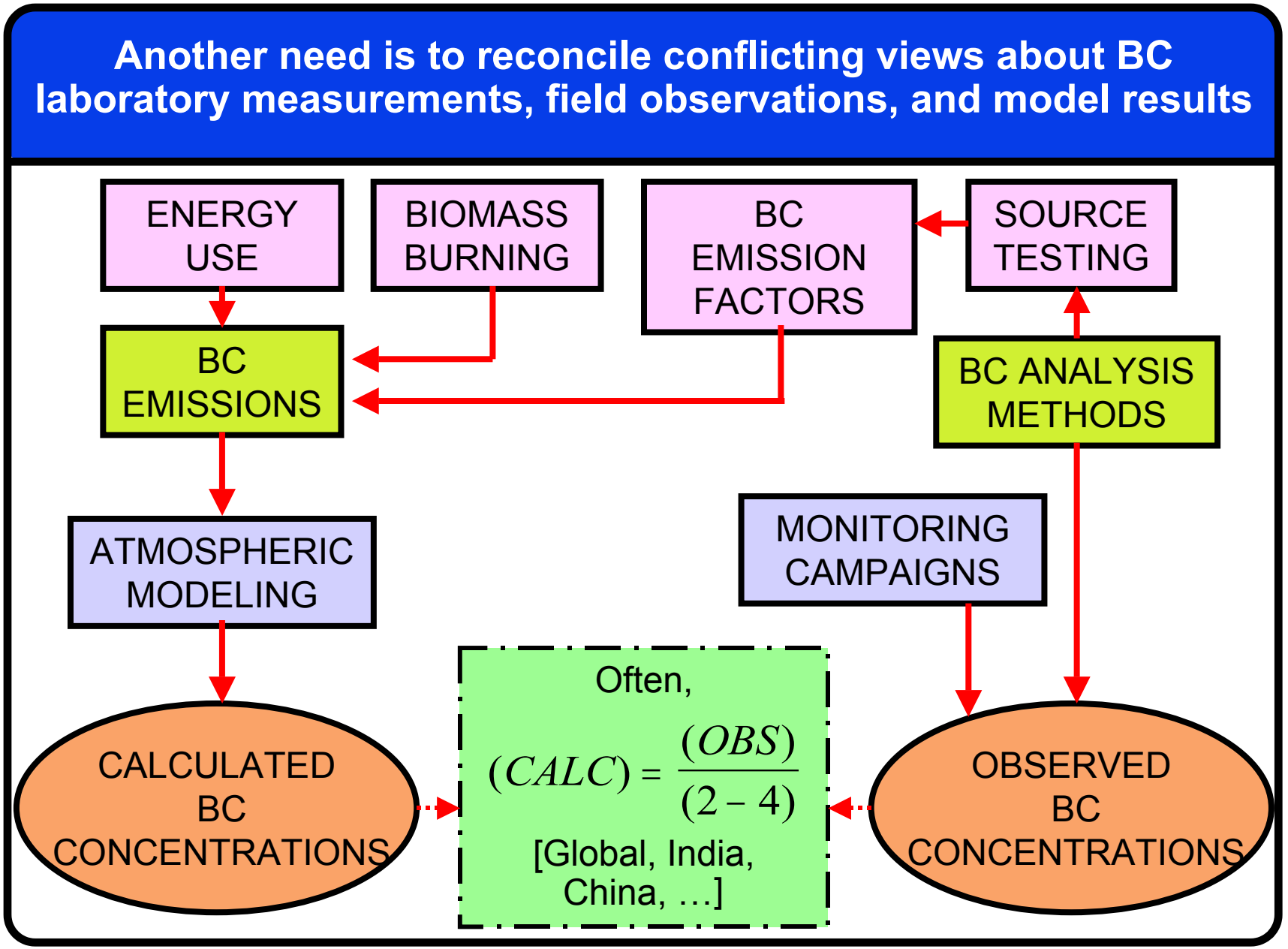
Big issue is the rate of penetration of better technologies in the future (or mix of technologies in the past)

Work in progress suggests that energy use will drive emissions up in the future, while improvements in technology performance will drive emissions down. It is likely that the net result will be stability or a decline in BC emissions in the future, depending on scenario (stay tuned)



Two urgent needs are to do more source testing in the developing world and to survey emitting sources

- Representativeness of entire population of sources
- Typical operating practices
- Typical fuels and fuel characteristics
- Relationship to similar sources in the developed world
- Daily and seasonal operating cycles


Another need is to reconcile conflicting views about BC laboratory measurements, field observations, and model results
ENERGY USE
BIOMASS BURNING
BC EMISSION FACTORS
SOURCE TESTING
BC EMISSIONS
BC ANALYSIS METHODS
ATMOSPHERIC MODELING
MONITORING CAMPAIGNS
CALCULATED BC CONCENTRATIONS
Often,
$(CALC) = \frac{(OBS)}{(2-4)}$
[Global, India, China, …]
OBSERVED BC CONCENTRATIONS

Documentation of the 1996 inventory is available in the form of the following paper:

"A Technology-Based Global Inventory of Black and Organic Carbon Emissions from Combustion"

T.C. Bond, D.G. Streets, K.F. Yarber, S.M. Nelson, J.-H. Woo, and Z. Klimont

in review

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(available from Tami Bond at yark@uiuc.edu)