Climate impact of black carbon emitted from energy consumption in the world's regions

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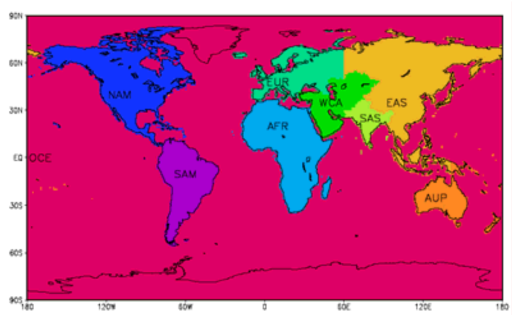
Abstract

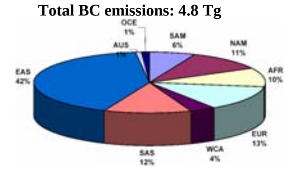
We have used Hadley Centre Climate Model (HADGEM2) and the Laboratoire de Méteorologie Dynamique General Circulation Model (LMD GCM) to estimate climate effects of black carbon (BC). The contribution of different regions to global BC atmospheric burden and direct radiative forcing (DRF) are estimated. On the global scale, fossil fuels and biofuels account for 66% and 34% of energy-related BC emissions, respectively. East and South Asia together contribute more than 50% of the global surface, atmospheric, and top-of-atmosphere DRF by BC. The regional contributions to global mean forcings closely follow the respective contributions to atmospheric burden. The global warming potential (GWP) of BC for different regions ranges from 374 to 677 with a global mean of 480. Europe is the largest contributor (63%) to BC deposition at high latitudes. The indirect GWP due to the BC effect on snow albedo is estimated to be largest for Europe (possibly as large as 1200), suggesting that BC emission reductions from this region are more efficient to mitigate climate change.

World Regions in LMD GCM

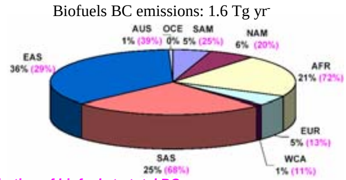


Energy Related BC Emissions

Total BC emissions: 4.8 Tg



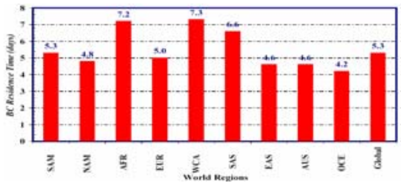
Biofuels BC emissions: 1.6 Tg yr

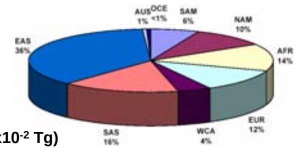


% contribution of biofuels to total BC emissions in the respective regions

BC Atmospheric Transport

Residence times





Atmospheric burden (6.97×10^{-2} Tg)

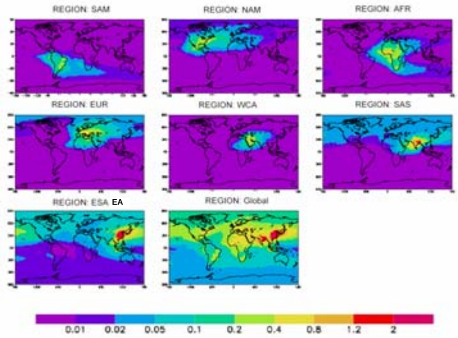
Inter Regional Transport

Contribution (%) of each region to BC load over different regions

RECEPTOR (columns) / SOURCE (rows)

Region	SAM	NAM	AFR	EUR	WCA	SAS	EAS	AUP	OCE
SAM	88.3	1.0	1.8	0.2	0.5	0.2	0.2	9.4	7.9
NAM	1.5	70.1	3.1	4.7	3.9	0.7	1.1	0.6	11.2
AFR	5.0	1.6	63.6	2.8	7.6	2.0	0.9	14.3	12.6
EUR	0.3	2.1	12.4	76.2	27.5	1.8	5.6	0.2	6.4
WCA	0.1	0.6	6.5	7.0	38.2	4.5	1.4	0.2	2.1
SAS	0.6	6.2	6.9	3.0	2.5	84.7	9.1	2.2	15.4
EAS	3.6	17.6	5.3	5.5	9.5	5.9	81.4	32.5	42.5
AUP	0.2	0.0	0.0	0.0	0.0	0.0	0.0	39.3	1.0
OCE	0.5	0.6	0.4	0.5	0.3	0.1	0.2	1.4	1.0

Direct Radiative Forcing (W m^{-2})



Global Warming Potentials of BC

Global warming potentials (GWPs) are used to compare the abilities of different greenhouse gases to trap heat in the atmosphere.

GWPs are based on the radiative efficiency (heat-absorbing ability) of each pollutant relative to that of carbon dioxide (CO_2), as well as the decay rate of each pollutant relative to that of CO_2 integrated over a time horizon (typically 100 years).

$$GWP_x = [\int_0^{\text{time horizon}} a_x\, r_x(t)\, dt / [\int_0^{\text{time horizon}} a_{CO2}\, r_{CO2}(t)\, dt]$$

a_x – radiative forcing per unit mass W kg^{-1}

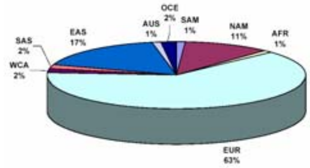
$r_x(t)$ is the time-dependent decay of pollutant following an instantaneous release of it at time t=0

BC Deposition on Snow and Ice

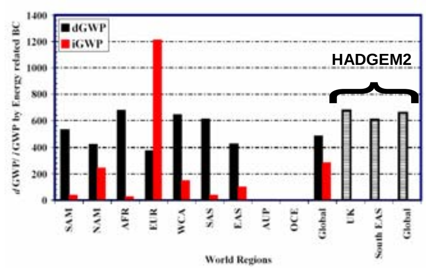
Radiative forcing from change in snow/ice albedo due to BC deposition ranges from +0.04 to +0.24 Wm^{-2}.

BC deposition to north to 60ºN and south to 60ºS is 5-10 mg m^{-2} with an annual deposition of 0.2 Tg.

Assumed direct forcing of +0.1 Wm^{-2} is apportioned to source regions according to how much BC is deposited north to 60°N and south to 60ºS. And indirect GWPs are calculated.



Global Warming Potentials of BC



European BC emissions have a factor of two larger GWP (*direct+indirect*) as compared to global emissions.

Conclusions:

- **Fossil fuels are the dominant source of BC over industrialised countries. Fossil fuels and biofuels are equally important over India and China.**
- **The atmospheric residence time for BC emissions from different regions varies between 4.6 to 7.3 days.**
- **The contribution to global mean forcing closely follows respective contributions to annual mean burden.**
- **There is a need to compare the climate effects of short-lived vs long-lived species for climate mitigation and air quality policies.**
- The Global GWPs for BC are model dependent. **There are large variations in GWPs for BC emissions from different regions, especially for *indirect* GWP; *direct* GWP: 374 to 678; *indirect* GWP: 38 to 1210.**
- **It would be more efficient to control BC emissions from Europe to mitigate climate change (due to snow effect).**
- **Further research is needed for climate feedbacks (in a slab ocean or coupled model, BC effect on snow/ice albedo) for regional and sectoral emissions to make these results stand on solid footing.**

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