An Inventory of Gaseous and Primary Carbonaceous Aerosol Emissions from India for the Ganges Valley Aerosol Experiment (GVAX)

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Background & Objectives

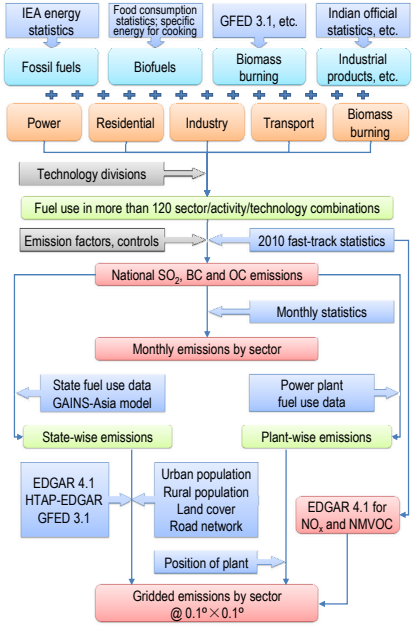
Background

- India is undergoing rapid industrialization.
- High aerosol concentrations and AOD values have been observed, as indicated by both ground- and satellite-based measurements.
- Aerosols are high in sulfate, nitrate, BC, and OC and are mostly from anthropogenic emissions.
- Increasing emissions have modified the regional climate through the direct and indirect radiative effects of aerosols.
- Energy consumption has increased substantially since 1990. However, few works estimate recent-year emissions.

Objectives

- Develop a new inventory of gaseous (SO_2, NO_x, and NMVOC) and primary carbonaceous aerosol (BC and OC) emissions from India in 2010.
- Support the GVAX campaign, which is designed to characterize aerosols, regional transport, and cloud-aerosol interactions in the Ganges Valley region of India.

Methodology



- SO_2, BC and OC:
  - *Emissions are estimated for 2008 by using a detailed technology-based methodology and extrapolated to 2010 based on fast-track statistics.*
- NO_x, NMVOC:
  - *Based on EDGAR4.1 and scaled to the year 2010.*
- Probability distributions are assumed for all the input parameters, and Monte Carlo simulations are used to analyze the emission uncertainties.

SO_2, BC and OC Emissions

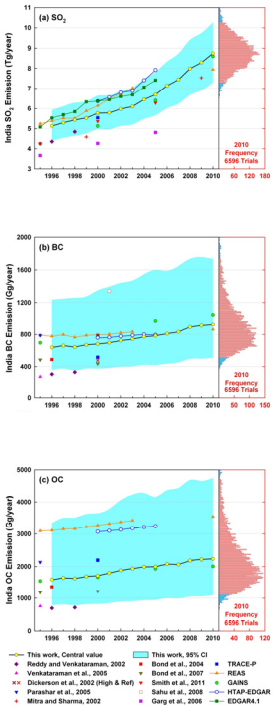
Emissions overview

SO_2, BC and OC emissions from India in 2010 (Unit: Gg/yr)

	SO_2	BC	OC
Power generation	5236 (-18%~19%)	5 (-83%~187%)	14 (-90%~234%)
Industry	2784 (-26%~28%)	227 (-57%~127%)	214 (-60%~118%)
Domestic	583 (-38%~47%)	579 (-60%~133%)	1946 (-58%~129%)
Transportation	144 (-17%~17%)	111 (-40%~53%)	54 (-36%~49%)
Subtotal	8747 (-17%~17%)	922 (-45%~88%)	2228 (-51%~113%)
Forest & savanna burning	17 (-54%~67%)	19 (-49%~82%)	157 (-41%~57%)
Agricultural waste burning	44 (-87%~113%)	74 (-47%~64%)	354 (-61%~107%)
Total	8807 (-16%~17%)	1015 (-41%~80%)	2739 (-44%~92%)

* The values in the parentheses indicate the 95% CI around the mean.

Comparison with previous work



Largest contributors to emission uncertainties

Fuel/Sector	% Variance	Contributors
Hard coal	60.3%	SC
Hard coal	28.5%	FU
Hard coal	3.3%	SR
Brown coal	2.7%	SC, FU, SR
Heavy fuel oil	2.2%	SC, FU
Diesel	0.7%	SC, FU
Industrial process	0.3%	Production, EF_{SO_2}
Other	1.9%	

* *SC: Sulfur content; FU: Fuel use; SR: Sulfur release ratio; EF_{SO_2}: SO_2 emission factor.*

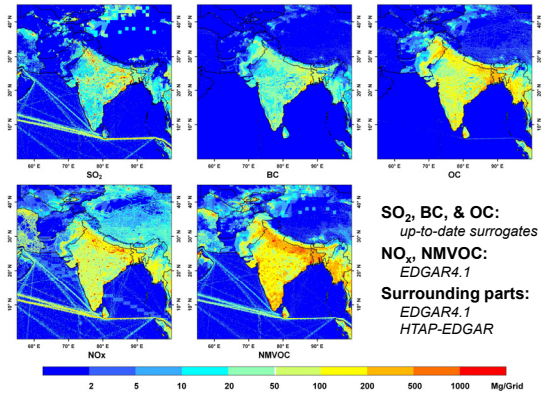
Fuel/Sector	% Variance	Contributors
Fuelwood/DO	63.3%	FU, tech, EF_{BC} (cook/heating stove)
Coal/IIN	14.1%	FU, tech, EF_{BC} (brick kiln, stoker)
Coal/DO	11.8%	FU, EF_{BC} (cookstove)
Crop waste/DO	1.8%	FU, EF_{BC}
Animal waste/DO	1.6%	FU, EF_{BC}
Diesel/TR	1.0%	FU, tech, EF_{BC} (superemitter, normal)
Coke making/IIN	0.9%	FU, tech, EF_{BC} (uncaptured)
Other	5.4%	

* *DO: Domestic; IN: Industry; TR: Transport; FU: Fuel use; tech: technology divisions; EF_{BC}: all parameters associated with BC emission factor.*

Fuel/Sector	% Variance	Contributors
Fuelwood/DO	88.5%	FU, tech, EF_{OC} (cook/heating stove)
Coal/DO	2.8%	FU, tech, EF_{OC} (cookstove, open fire)
Crop waste/DO	2.6%	FU, EF_{OC}
Coal/IIN	1.6%	FU, tech, EF_{OC} (brick kiln, boiler)
Animal waste/DO	0.7%	FU, EF_{OC}
Biofuel/IIN	0.2%	EF_{OC}
Other	3.6%	

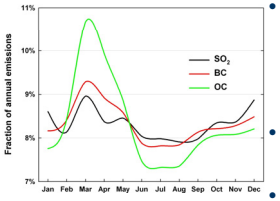
* *DO: Domestic; IN: Industry; TR: Transport; FU: Fuel use; tech: technology divisions; EF_{OC}: all parameters associated with OC emission factor.*

Gridded Emissions @ $0.1^0 \times 0.1^0$



SO_2, BC, & OC: *up-to-date surrogates*
NO_x, NMVOC: *EDGAR4.1*
Surrounding parts: *EDGAR4.1 HTAP-EDGAR*

Seasonality of Emissions



- Monthly statistics of…
  - *Power generation* — **Power**
  - *Industrial production* — **Industry**
  - *Passenger & freight volume transported by ship, railway & aviation* — **Transport**
- A dependence of stove operation on regional monthly mean temperature — **Domestic**
- GFED v3.1 — **Open biomass burning**

Conclusions

- SO_2, BC, and OC emissions for India in 2010 are 8.81 Tg, 1.02 Tg, and 2.74 Tg, respectively, and the 95% confidence intervals for these estimates are -16% to 17% for SO_2, -41% to 80% for BC, and -44% to 92% for OC.
- Coal-fired power plants and traditional cookstoves are the main sources of SO_2 and carbonaceous aerosols, respectively.
- The major contributors to emissions uncertainty in India are coal sulfur content for SO_2 (60%) and fuelwood emission factors of traditional cookstoves for BC (56%) and OC (65%).

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Acknowledgments

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