Multi-Satellite Observations of NO_x Emissions Increase in Indian Thermal Power Sector from 1996 to 2010

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Background & Objective

Background

- India is the second largest NO_x emitting country in Asia
  - ➢ *~16% of total Asian emissions*
- Thermal power plants are the most important point sources in India
  - ➢ *~30% of the national NO_x emissions*
- Due to the rapid economic growth and the absence of regulations, NO_x emissions in the Indian power sector have increased dramatically since the mid-1990s. However, few previous studies…
  - ➢ *present year-by-year trends with up-to-date activity rates*
  - ➢ *applied fuel/boiler-size/control specific NO_x emission factors, but used default IPCC emission factors to all power plants*
  - ➢ *used activity rates at the plant or unit level, but instead at the country or state level*
- Tropospheric NO_2 columns retrieved from satellites have been successfully applied to identify and constrain NO_x emissions from large thermal power plants. However,…
  - ➢ *there have been very few quantitative applications to India*

Objective

- Use a unit-based methodology to develop new NO_x emission inventories for Indian power plants during 1996–2010
- Examine the India NO_x emission trend of thermal power plants during 1996−2010 from the viewpoints of both unit-based inventories and multi-satellite observations
- Study the effect of the large NO_x releases from the power sector to the Indian atmospheric environment for recent years

Methodology & Data Sets

Unit-wise Activity Rates and Information

- All Indian thermal power units with capacity >20 MW are included
  - ➢ *> 800 units*
  - ➢ *geographical location, boiler size (capacity), fuel type, electricity generation, specific fuel consumption, exact time when the unit came into operation and/or retired, etc.*

NO_x Emission Factors (EFs) and Control Scenarios

- For coal-fired units:
  - ➢ *NO_x emissions are not regulated in India for coal-fired power plants. Five emission scenarios are generated to reflect possible alternative NO_x emission situations*

Boiler-size-specific and emission-control-specific EFs

Boiler size	LNB *	EFs (g/GJ)	Source	Emission scenarios					
				S1	S2	S3	S4	$S5_{<1996}$	$S5_{>1996}$
Not classified		300	IPCC, 2006	X					
<100 MW	w/o	308	Zhao et al., 2008		X	X	X	X	
	w/	177	Estimated **						X
100−300 MW	w/o	330	Zhao et al., 2008		X	X		X	
	w/	188	Zhao et al., 2010				X		X
≥300 MW	w/o	410	IPCC EFDB, 2012		X			X	
	w/	236	Zhao et al., 2008, 2010			X	X		X

* LNB: low-NO_x burner. ** Assuming the average removal efficiency of the LNB devices is 43%.

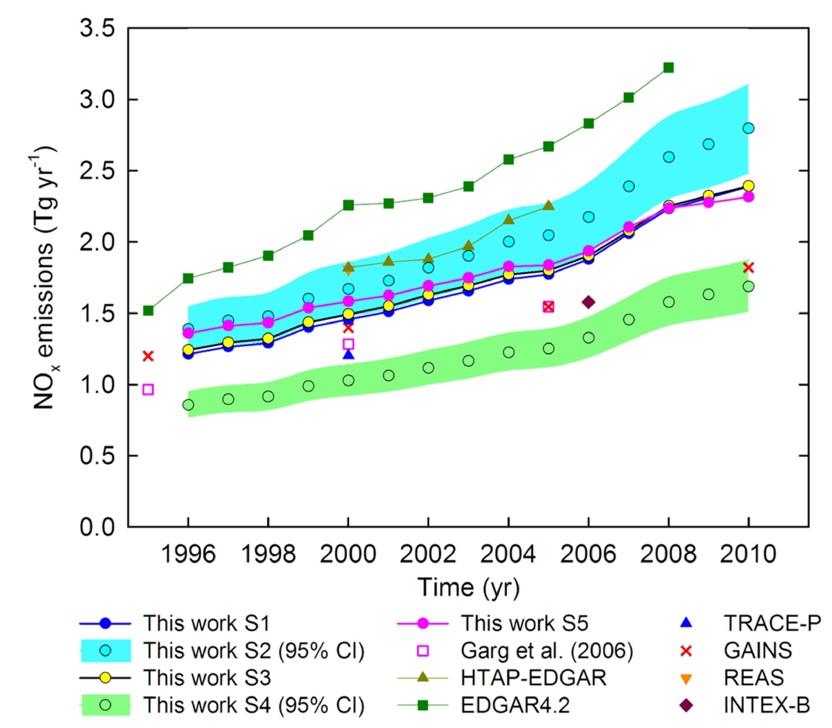
- For gas-fired and oil-fired power plants:
  - ➢ *India has emission standards varying with the unit age and size*

NO_x Emissions from Power Plant i (Mg/yr)

$$E_i = \sum_j \sum_k \sum_l \sum_m \left(G_{i,j,k} \times \mathrm{SFC}_{i,j,k} \times \mathrm{NCV}_j \times \mathrm{EF}_{j,l,m} \times 10^{-9} \right)$$

j: Fuel type; k: Boiler size; l: Unit; m: Control technology; G: Electricity generation (kWh/yr); SFC: Specific fuel consumption (kg/kWh); NCV: Net calorific value (MJ/kg); EF: NO_x emission factor (g/GJ)

NO_x Emissions from Power Plants



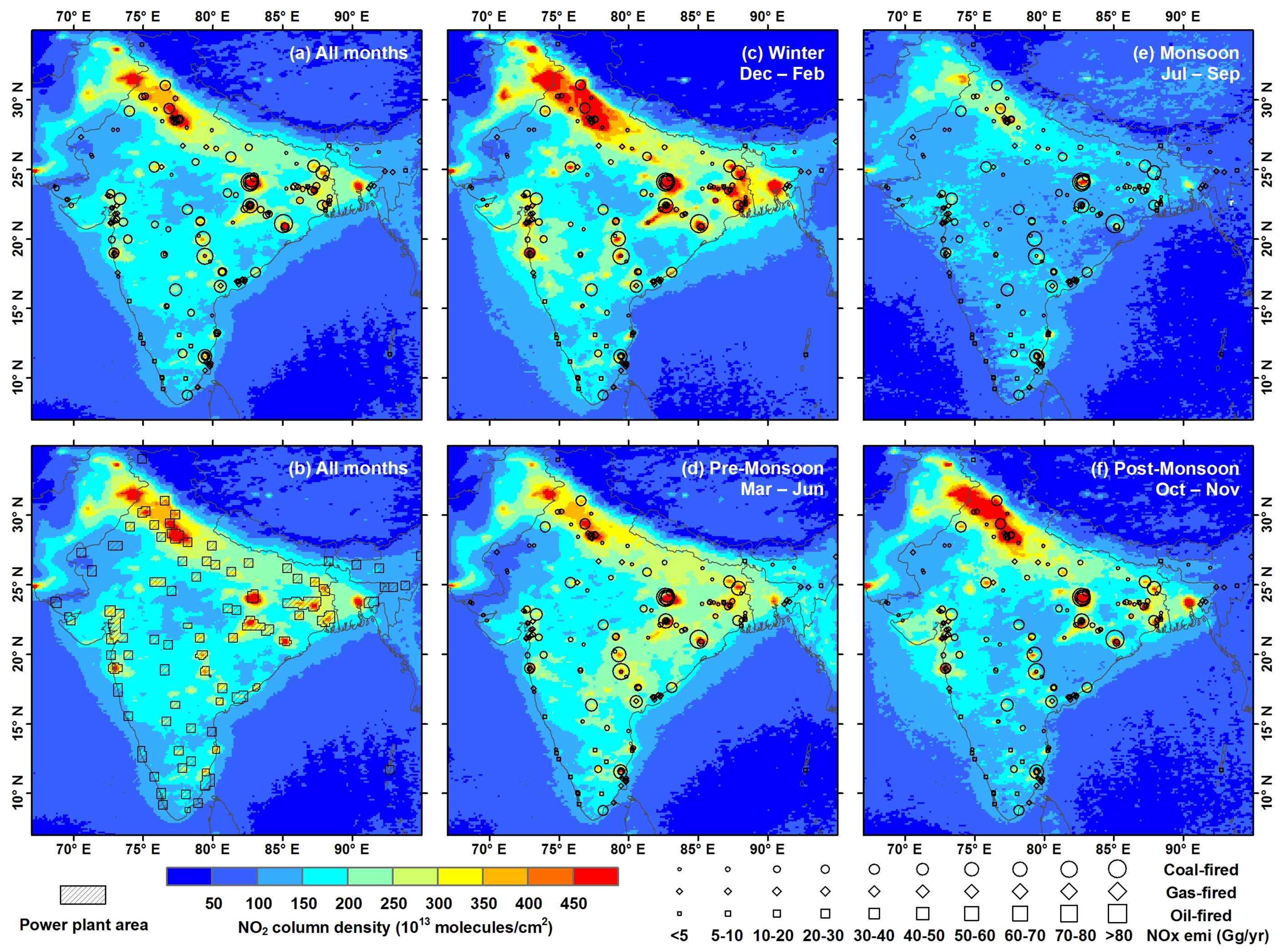
- *NO_x emissions 1996-2010*
  71−103% increase
- *By fuel type*
  ~95% from coal-fired units
  ~4% from gas-fired units
  ~1% from oil-fired units
- *Emission uncertainties due to uncertainties in activity and EFs alone*
  ±11~15%
- Compared to activity rates and EFs, LNB-related parameters seem to be a more crucial factor that influences the accuracy of NO_x emission estimates in India

NO_2 Observed from Space

NO_2 Tropospheric Vertical Column Densities (TVCDs)

- OMI — *Monthly level 3, KNMI, DOMINO v2.0* — *2005-2010*
- SCIAMACHY — *Monthly level 3, KNMI, TM4NO2A v2.0* — *2003-2010*
- GOME-2 — *Monthly level 3, KNMI, TM4NO2A v2.1* — *2007-2010*
- GOME — *Monthly level 3, KNMI, TM4NO2A v2.0* — *1996-2002*

Spatial distribution of power plants NO_x emissions and OMI NO_2 TVCDs

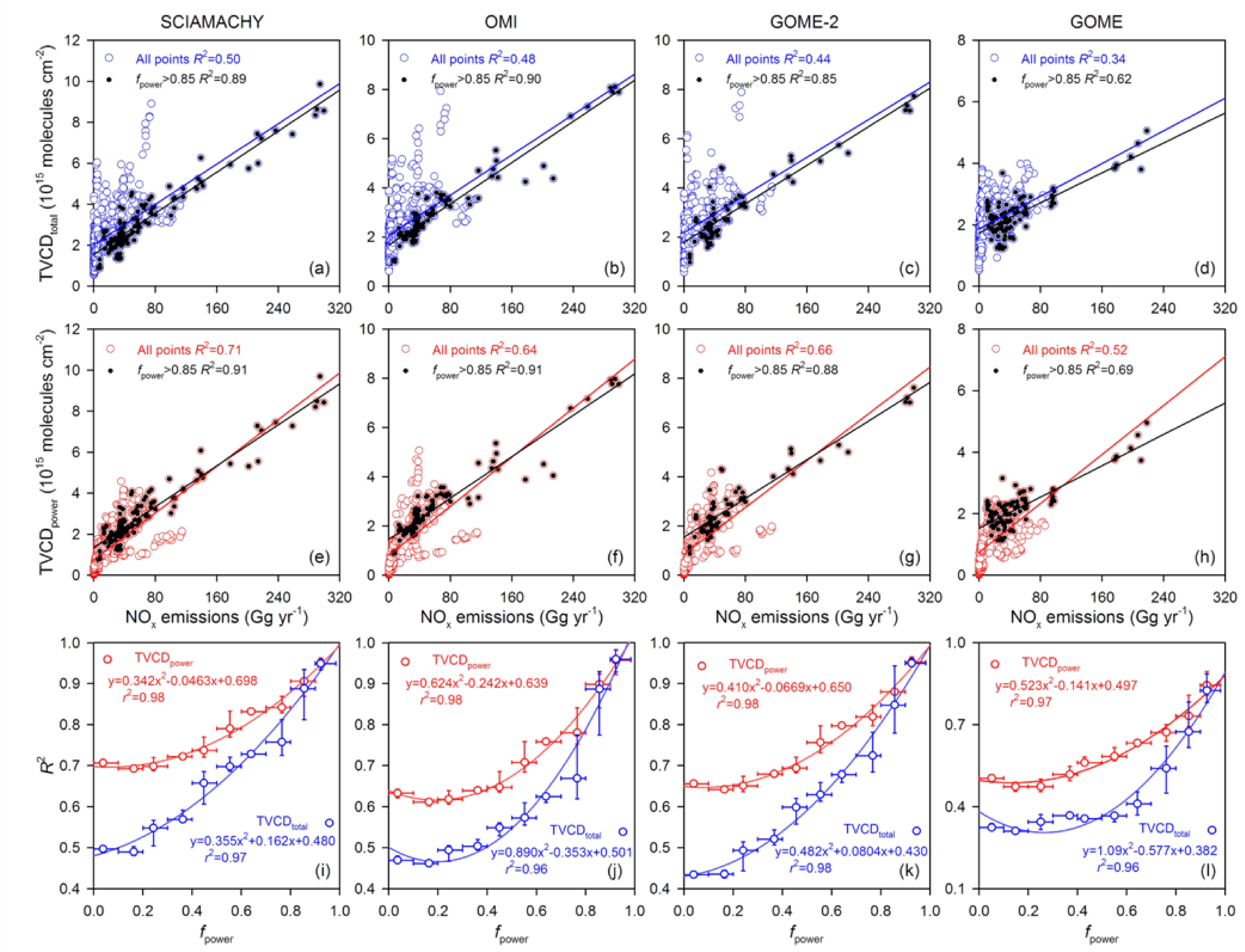


- A number of satellite NO_2 hot spot are observed over India, and they match the locations of power plants reasonably well
- Seasonality
  - ➢ *NO_2 columns are high in winter and low in the monsoon season*
- Combining the adjacent plants, 81 power plant areas were defined
- For power plant area n, NO_2 TVCD attributed to emissions from thermal power plants ($\mathrm{TVCD_{power}}$) is calculated by:

$$\mathrm{TVCD}_{\mathrm{power},n} = f_{\mathrm{power},n} \times \mathrm{TVCD}_{\mathrm{total},n} = \frac{E_{\mathrm{power},n}}{E_{\mathrm{total},n}} \times \mathrm{TVCD}_{\mathrm{total},n}$$

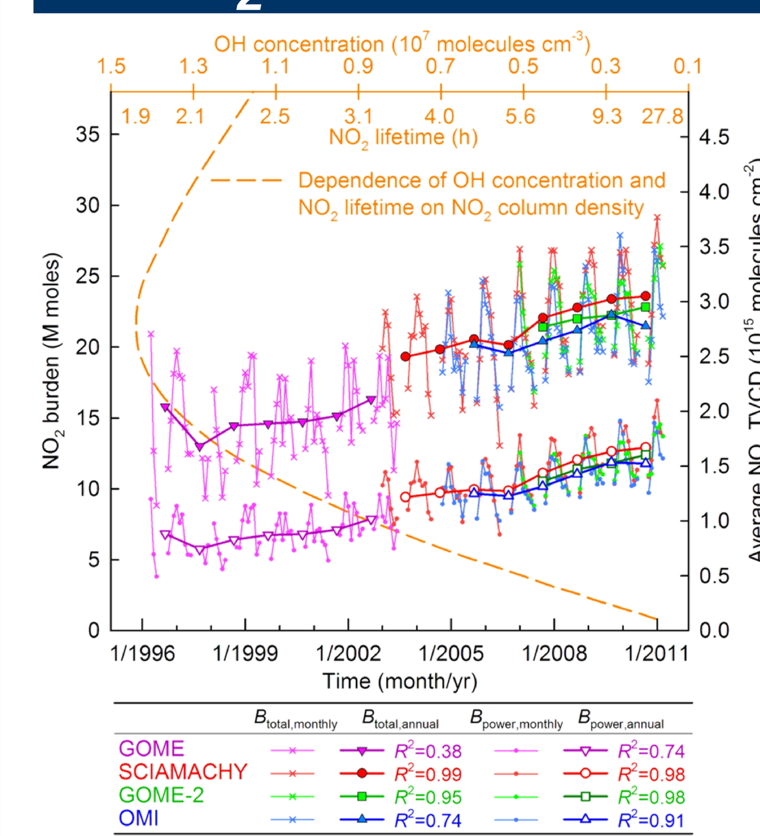
  - ➢ *Gridded emissions of other sources were taken from EDGAR4.2 for the year 2005 and scaled to 1996−2010 based on the GAINS inventory*

NO_x emissions vs. NO_2 columns over power plant areas & R^2 vs. f_{power}



- E_{power} correlates better with $\mathrm{TVCD_{power}}$ than $\mathrm{TVCD_{total}}$
- Correlations are better for areas dominated by power plant emissions

NO_2 Trends over Power Plant Areas



- ***Lamsal et al. (2011)*** *used a dimensionless factor β to establish the relationship between changes in surface NO_x emissions and changes in NO_2 TVCD*

$$\beta = \frac{\Delta E_{\mathrm{total}}/E_{\mathrm{total}}}{\Delta \mathrm{TVCD}_{\mathrm{total}}/\mathrm{TVCD}_{\mathrm{total}}}$$

$\beta > 1$, clean (low NO_2) region
$\beta < 1$, polluted (high NO_2) region

Period	Instruments	Ave. β
1996−2002	GOME	1.60
2003−2005	SCIAMACHY	2.27
2005−2007	SCIAMACHY	1.02
	OMI	2.37
2007−2010	SCIAMACHY	0.66
	OMI	0.81
	GOME-2	0.66

β~2 → β~0.7

- The overall NO_x chemistry over Indian power plant areas has changed considerably in the past few years
- NO_x pollution in India becomes more and more serious

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