Influence of coal based thermal power plants on aerosol optical properties in the Indo-Gangetic basin

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[1] The Indo-Gangetic basin is characterized by dense fog, haze and smog during the winter season. Here, we show one to one correspondence during the winter season of aerosol optical properties with the location of thermal power plants which are single small spatial entities compared to the big cities. Our results indicate that power plants are the key point source of air pollutants. The detailed analysis of aerosol parameters deduced from the Multiangle Imaging SpectroRadiometer (MISR) level 3 remote sensing data show the existence of absorbing and non-absorbing aerosols emitted from these plants. Analysis of higher resolution Moderate Resolution Imaging Spectroradiometer (MODIS) level 2 aerosol optical depth over thermal power plants supports the findings. **Citation:** Prasad, A. K., R. P. Singh, and M. Kafatos (2006), Influence of coal based thermal power plants on aerosol optical properties in the Indo-Gangetic basin, *Geophys. Res. Lett.*, *33*, L05805, doi:10.1029/2005GL023801.

1. Introduction

[2] Recent studies using satellite (MODIS, MISR, POLDER (Polarization and Directionality of the Earth's Reflectances), TOMS (Total Ozone Mapping Spectrometer)) and AERONET (Aerosol Robotic Network) measurements show higher aerosol optical depth (AOD) over the Indo-Gangetic (IG) basin representing the intense air pollution that persists throughout the year and show strong variability with season [*Goloub et al.*, 2001; *Di Girolamo et al.*, 2004; *Singh et al.*, 2004; *Massie et al.*, 2004; *Prasad et al.*, 2004, 2006]. A statistically significant increase in aerosols up to 10.6 ± 4.9% per decade has been calculated for the Indian region [*Massie et al.*, 2004] based on TOMS aerosol records (1979–2000). A major source of natural and anthropogenic mineral dust aerosols [*Tegen and Fung*, 1995; *Tegen and Miller*, 1998] in the IG basin is wind laden dust transported from the Thar desert in India and the arid or desert regions of the Middle East [*El-Askary et al.*, 2004, 2006; *Prasad et al.*, 2004, 2006] during the summer season. During the winter season, the anthropogenic aerosol components, especially sulfates and black carbon (BC), are most discernible due to substantially lower contribution from sources of natural aerosols such as mineral dust etc [*Tegen and Fung*, 1995, 1998; *Di Girolamo et al.*, 2004; *Massie et al.*, 2004]. The increase in the SO_2 emissions for India (47% per decade) and China (35% per decade) is reported by *Massie et al.* [2004] based on SO_2 emission inventory [*Smith et al.*, 2001; *Streets et al.*, 2003] for 20 years (1980–2000). This is in agreement with the rate of growth of SO_2 emissions during the 1990's as estimated by *Garg et al.* [2001] (5.5% per year) and *Streets et al.* [2001] (4.9% per year). The consumption of coal, petroleum products, and biofuel has increased with the increasing population, as a result the emission of sulfates, and BC concentration have also increased significantly [*Garg et al.*, 2001; *Menon et al.*, 2002; *Reddy and Venkataraman*, 2002; *Gadi et al.*, 2003; *Venkataraman et al.*, 2005]. An increase in the concentration of BC is of special interest to atmospheric scientists because of its potential climatic impact on the hydrological cycle. This could produce changes in the monsoon (rainfall) patterns and abnormal heating of the atmosphere as BC is strongly absorbing in nature [*Ramanathan et al.*, 2001; *Menon et al.*, 2002; *Ramanathan and Ramana*, 2005; *Venkataraman et al.*, 2005] (IPCC reports, http://www.grida.no/climate/ipcc_tar/). An increased anthropogenic aerosol in the Indian sub-continent (especially sulfates and BC) is mainly attributed to increasing consumption of petroleum products and bio-fuel [*Di Girolamo et al.*, 2004]. In fact, large scale uncontrolled urbanization and industrial development in the IG basin have caused high pollution levels in air, water and land. India is the third-largest producer of coal in the world (365 million tons, 2003–04), where the coal used in the power plants is of poor quality (mostly E-F grade or lignite) with high ash content (35–50%) and low calorific value (http://www.eia.doe.gov). The total pollution load from the transport sector is quantitatively second to the thermal power sector (http://envfor.nic.in/soer/2001/ind_air.pdf). The use of biofuels in cooking is decreasing, as a result its percent contribution towards BC emission is declining in India (Figure 1b) (http://pubs.wri.org). The emission fluxes (kg $km^{-2}yr^{-1}$) of $PM_{2.5}$ are primarily due to fossil fuel combustion in the IG basin (G. Habib et al., Seasonal and interannual variability in absorbing aerosols over India derived from TOMS and sunphotometer: Analysis with regional meteorology and emissions, submitted to *Journal of Geophysical Research*, 2005, hereinafter referred to as Habib et al., submitted manuscript, 2005). The use of other sources of energy for cooking, such as gas, electricity and petroleum products, has been increasing especially in fast growing suburbs and in rural areas. A large number of thermal power plants (TPPs) are located in the northern part of India (Figures 1a and 3).

[3] The intense fog, haze, and smog are big problems especially in the northern plains during the winter season and bring day to day life to standstill [*Piketh and Walton*,

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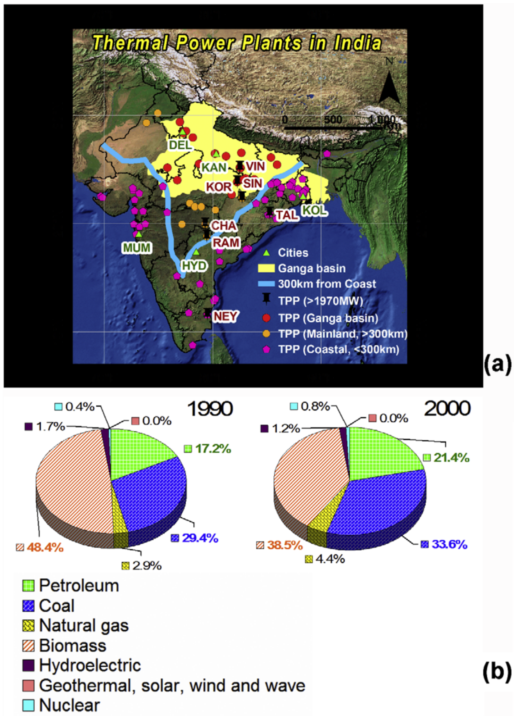

Figure 1. (a) Location of cities, Ganga (IG) basin, TPPs (>1970 MW) and all TPPs >100 MW in India. (b) India's percent share of major energy sources (1990 and 2000, http://pubs.wri.org). Name of cities (DEL = Delhi, KAN = Kanpur, KOL = Kolkata, MUM = Mumbai, HYD = Hyderabad) and mega power plants (TAL = Talcher, SIN = Singrauli, KOR = Korba, RAM = Ramagundam, VIN = Vindhyachal, NEY = Neyveli, CHA = Chandrapur).

2004]. Coal is considered a heavily polluting fuel in terms of black carbon, sulfates and other gaseous pollutants primarily due to incomplete and inefficient combustion. Here, we present analysis of aerosol parameters over TPPs and major cities during the winter season (December and January). Based on the analysis, we show that coal fired TPPs are one of the biggest sources of anthropogenic air pollution. The comparison of aerosol parameters over major cities, where combustion of petroleum products is another major source of atmospheric pollutants, also supports our findings.

2. Aerosol Optical Depth Over the IG Basin, and its Relation to Dense Fog, Haze, and Smog

[4] Recently, higher optical depth has been found over the IG basin during the winter season [*Di Girolamo et al.*, 2004; *Prasad et al.*, 2004, 2006; *Ramanathan and Ramana*, 2005] using MODIS and MISR data. *Ramanathan and Ramana* [2005] have shown the persistence of high AOD over different parts of the IG basin, which depends on the meteorological parameters and topography of the basin. *Singh et al.* [2004] have recently presented a detailed seasonal analysis of aerosol parameters over Kanpur based on AERONET data. The single scattering albedo (SSA) retrieved from AERONET during the winter season (December–January–February, 2001–2005) shows the presence of absorbing (BC) (low SSA 0.64–0.88, 443–673nm, coarse mode) and non-absorbing (sulfate) (high SSA >0.93, fine mode) aerosols. High imaginary parts (>0.012) of the refractive index during winter [*Singh et al.*, 2004] also indicate the presence of strongly absorbing aerosols (BC).

3. Thermal Power Plants in India

[5] In India, there are more than 89 TPPs (Figure 1a and Table S1) having capacity >100 MW (http://www.energymanagertraining.com/power_plants/Power_stations.htm), apart from other smelter and industrial units that consume a large amount of coal per month.[1] Coal is a major source of energy in India (http://www.eia.doe.gov/emeu/cabs/indiaenv.html). The energy consumption has increased 208% from 4.16 quadrillion Btu (quads) in 1980 to 12.8 quads in 2001. Coal percent share has increased from 29.4% to 33.6% in the last decade (1990–2000) as a major energy source whereas the share of biomass has declined by 9.9% in the same period (http://pubs.wri.org) (Figure 1b). India is fifth (in the year 2001) in the world in carbon emissions (251 million metric tons of carbon equivalent) (http://www.eia.doe.gov/emeu/cabs/indiaenv.html). Emission levels in these coal based power plants are high especially from old units [*Sharma et al.*, 2003; G. Habib et al., submitted manuscript, 2005] (Table S2). The emission rate is found to reduce from 500–1,000 to 10–20 $\mu g/m^3$ in a 50 year old Calcutta Electric Supply Corporation (CESC) power plant (160 MW) after its improvement (http://www.usaep.org/accomplishments/india.htm).

4. Aerosol Parameters

[6] We have examined MISR Level-3 (MIL3MAE) stage 2 validated monthly average aerosol parameters (AOD, angstrom exponent, SSA) (spatial resolution 0.5 degree) for the winter season (December–January, 2000–2005) (http://www-misr.jpl.nasa.gov/) [*Kahn et al.*, 2005]. MISR angstrom exponent and SSA data are currently qualitative indicators, since these data are only Beta validated. We have analyzed data for winter season since desert dust and monsoon rainfall are absent, and the anthropogenic aerosol component is maximum [*Massie et al.*, 2004, *Prasad et al.*, 2006]. Large variations of AOD are found along N-S and E-W across India [*Prasad et al.*, 2004, 2006], therefore for inter-comparison of AOD over TPPs (and cities) situated in different parts of India, a common background AOD level cannot be used. Hence, we have extracted AOD over TPP and city locations (1 × 1 window value) and compared with their surroundings (3 × 3 or 5 × 5 window value). The size of window suitable for background AOD measurement is taken in accordance with spatial resolution of satellite data, which is 0.5 degree for MISR (3 × 3 window) and 10 km for MODIS L2 data (5 × 5 window). Aerosol parameters over major cities and mega TPPs (>1970 MW) (Figure 2) are extracted over 1 × 1 (point feature average) and 3 × 3 (surrounding or background average) pixels representing 0.5 × 0.5 degree and 1.5 × 1.5 degree area, respectively

[1] Auxiliary material is available at ftp://ftp.agu.org/apend/gl/2005GL023801.

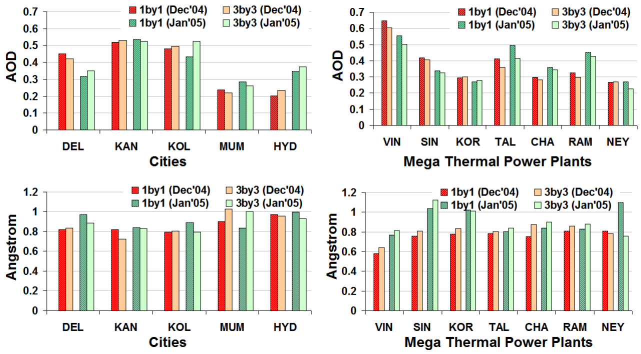

Figure 2. MISR (0.5 degree spatial resolution) AOD and angstrom over major cities and mega thermal power plants (>1970 MW). Name of cities and TPPs are abbreviated as first three letters in caps as in Figure 1a.

(Figure 1a). Summation of MISR AOD (τ_{MISR}) is performed over all TPPs (1 × 1 and 3 × 3 windows) located in the IG basin (Figure 1a) for the period December–January 2000–2005 excluding coastal TPPs. $\Sigma\tau_{MISR(1by1)}$: $\Sigma\tau_{MISR(3\times3)}$ is found to be 97.58: 97.00 for all TPPs in the IG basin (excluding coastal TPPs). We have found that multi-year MISR Level-3 AOD suggests TPPs as point source of pollution especially for large units in the IG basin.

[7] To verify the MISR AOD observations (2000–2005), summation of MODIS Level-2 AOD having higher spatial resolution of 10 km have been carried out. $\Delta\tau_{MODIS}$ (= $\tau_{MODIS(1\ \times\ 1)} - \tau_{MODIS(5\ \times\ 5)}$) was calculated over all TPPs (>100 MW) located in the IG basin using MODIS Level-2 swath product (MOD04_L2) (mean of 45 overpasses during December 2004). $\Delta\tau_{MODIS(max.)}$ over TPPs in northern India including the IG basin is mostly significant compared to the associated error in measurement (Figure 3 and Table S3). There is uncertainty of $\pm 0.05 \pm 0.15\tau$ in MODIS AOD measurement over land [*Remer et al.*, 2005]. Error in measurement is found to be mostly less than $\Delta\tau_{MODIS(max.)}$ value signifying TPPs as a major point source of pollution. This quantitatively corroborates the qualitative observations as obtained earlier from 0.5 degree resolution MISR data (Figure 2). Table S4 and Figure S1 lists mean of $\Delta\tau_{MODIS}$ (for all individual $\Delta\tau_{MODIS}$ observations >0.1 or <−0.1) in decreasing order along with standard deviation and count as well as similar statistics for all observations over TPPs in the northern India. Some TPPs located near Kolkata, show negative $\Delta\tau_{MODIS}$, which may be due to its close proximity to the ocean (Figures 1a and 3). Summation of MODIS AOD over TPPs and major cities (Table S5 and Figure S2) support above findings. TPPs located in major steel producing cities with huge smelters show very high $\Delta\tau_{MODIS(max.)}$. Korba STP (2100 MW) show comparatively lower $\Delta\tau_{MODIS\ (max.)}$ and it could be due to presence of other TPPs in its vicinity raising regional AOD thus affecting 5 × 5 window average.

[8] The MISR AOD is mostly higher over major TPPs (1 × 1 window) than cities (1 × 1 window) compared to their respective surroundings (3 × 3 window). The MISR angstrom exponent is mostly lower over mega TPPs (1 × 1 window) whereas generally higher over major cities (1 × 1 window) compared to their respective surroundings (3 × 3 window) with few exceptions (Figure 2). Cities (Mumbai, Kolkata) and TPPs (Neyveli, TPPs near Kolkata) located close to the coast do not show the above trend which was also found to be true with MODIS L2 data over TPPs (Figures 2 and 3).

[9] MISR SSA are mostly high over mega TPPs (1 × 1 window), but are relatively low over major cities (1 × 1 window) compared to their respective surroundings (3 × 3 window) (Figure S3). Delhi follows a common trend where SSA is low compared to its surroundings during December 2004 and January 2005. Delhi is a metropolitan city with much higher population (13.78 million in 2001, http://www.censusindia.net) and total vehicles (>3.2 million) compared to other cities. Due to higher consumption of petroleum products, especially diesel, Delhi is likely to yield more BC, in addition to the emissions from TPPs. This indicates the influence of petroleum and coal combustion from the transport, industrial and power sectors.

5. Conclusions

[10] Integrated analysis of aerosol parameters, specifically AOD, angstrom and SSA from MISR Level 3 and AOD from MODIS Level 2 data during the winter season shows one to one correspondence with almost all TPPs >100 MW. These are single small spatial entities compared to big cities, but, by consuming thousands of tons of coal daily, they contribute heavily in terms of air pollutants. AOD is distinctly high over TPP locations. Relatively coarser particles, having lower angstrom exponent, are present over major TPP locations compared to major cities. Interestingly, SSA is also found to be higher over major TPPs compared to surroundings. The effect of burning of petroleum products is also visible over major cities. Coal-based TPPs are found to affect aerosol and BC concentrations. Cleaner-burning TPPs would produce a quantitatively bigger pollution reduction especially in populated areas rather than spending same money on urban pollution sources. Therefore, preference should be given to technological-operational improvement in these heavily polluting TPPs along with promotion of cleaner sources of energy to reduce the pollutant load in the atmospheres over India and China.

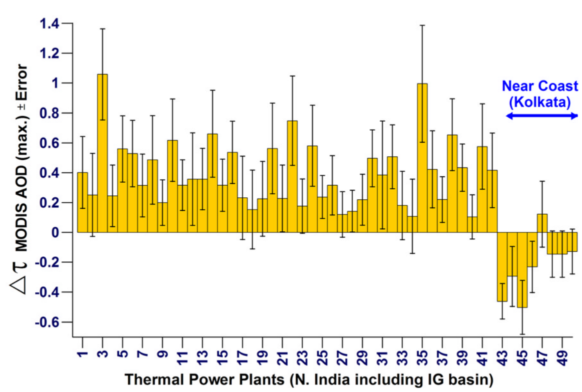

Figure 3. $\Delta\tau_{MODIS}$ (MODIS level-2 AOD) over TPP in the Ganga (IG) basin (yellow polygon). Symbol index is same as Figure 1a. The $_{(max.)}$ ± error is positive and significant over TPPs in northern India including IG basin. Table S3 gives value and name of TPPs.

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