Satellite observed regional distribution of tropospheric nitrogen dioxide (NO_2) and carbon monoxide (CO) over the Indian sub-continent

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Introduction

Industrialization, urbanization and rapid traffic growth has contributed significantly to economic growth in India. This is believed to be responsible for increasing emissions of gaseous pollutants over the past two decades. However, this development has not been uniform. Large regional variability exists in population density, industrialization, urbanization, resource-use levels and energy consumption pattern, creating regions of high air pollution. Pockets of heavy pollution are being created by emissions from major industrial zones and mega-cities (where vehicle numbers are rapidly increasing). In this study, we investigate the spatial distribution of satellite observed NO_2 (GOME and SCIAMACHY) and CO (MOPITT) over the Indian sub-continent, calculate the trends in the tropospheric NO_2 over a hot-spot regions, and pollutant (in this case CO) transport pathway from Indian region. Further, we compare the satellite observed regional distribution of NO_2 and CO over India with the distribution of NO_X and CO sources from the bottom-up emission inventories.

Abstract

NO_2-hotspots in India can precisely be identified as a localized source of NO_2 and mostly found to be associated directly to the large cities, industrial areas or large thermal power plants. Fast-growing industrial regions show large trends compared to other regions in India. Seasonal variations show a maximum NO_2 during winter-summer (Dec-May) and a minimum during the monsoon (June-Sept). The observed seasonal cycle in satellite-derived NO_2 agrees well with the surface-level observations of NOx.

MOPITT retrievals at 850 hPa show high concentration of CO over Indio-Gangetic region and strong source area over the eastern part. High CO levels in the mid-troposphere indicates the vertical transport from northeast India. Further, MOPITT retrievals at 350 hPa show that Asia pollution plumes from India can reach to Mediterranean and Africa via westward transport with the monsoon circulation. Transport of the CO over Arabian Sea and Bay of Bengal generated by the winter monsoon outflow from South Asia has also been observed.

Regional distribution of NOx and CO observed over India from the emission inventory is quite similar to that observed in the satellite measurements .

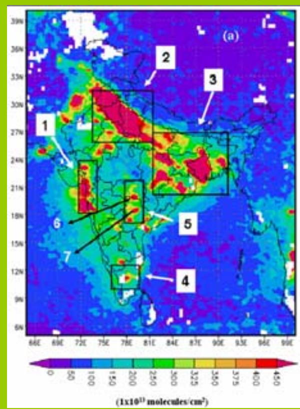
Satellite observations

Tropospheric NO_2 column data available at http://www.temis.nl/airpollution/no2.html is used in this study.
GOME (ERS-2): 1996-2002
SCIAMACHY (ENVISAT): 2003-2006

Monthly CO Profiles available at http://eosweb.larc.nasa.gov/
MOPITT (Terra): 2000-2007

Pollution Hot-spots in India and trends during past decade (1996-2006)

SCIAMACHY tropospheric NO_2 over India (Dec. 2003-2006 average)



- Region 1 and Indo-Gangetic (IG) plain (2 & 3) shows high NO_2 levels, as well as wide spread of emission hotspots.
- High NO_2 concentrations over the (IG) region is due to coal based thermal power plants, steel, sugar, and other small and medium industries (several of which use coal as fuel), transport and open burning of litter and biofuels used for domestic cooking in rural areas which is scattered over the entire region.

Regional Trend

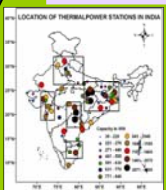
Regression model: $\theta(t) = a(t) + b(t)$ .Trend (t) + resid (t)
Where, t = Month index (1996-2006), $\theta(t)$ = Time series NO_2.
b(t) = Seasonal cycle coefficient, A(t) = Seasonal trend coefficient
Res(t) = Residual error time series for regression model

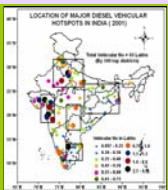
Regions	Trends (% per year)
1. Mumbai-Gujarat industrial corridor	2.1 ±1.1
2. Delhi Region	2.4± 1.2
3. East northeastern India coal mine	1.6 ±0.9
4. Southern India region	1.4 ±1.2
5. Central India	1.24 ±1.1
India as whole	1.65 ±0.5

Point Sources: Large thermal power plants at Chandrapur(6) and Rgundam (7) with installed capacity of ~2300 and ~2200 MW respectively

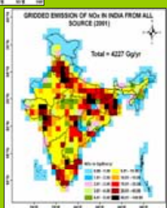
(Ghude et al., JGR, 2008)

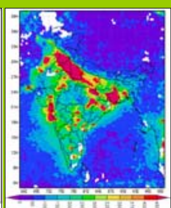
Regional spread of large point sources and comparison with NOx emission inventory



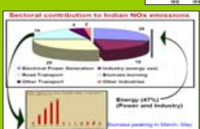


- Regional spread of high NO_2 concentrations correlate well with the locations of Thermal power plants and major diesel vehicular hotspots in India.
- This has a close correspondence with coal and petroleum consumption pattern of India.
- Approximately 70% of all of India's coal consumption is used for power generation and contributes ~45% of total NOx emission.
- Gasoline and diesel are the primary fuels for automobiles and contributes another 32% of NOx emissions.





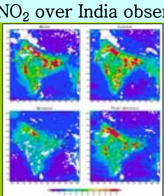
Population density

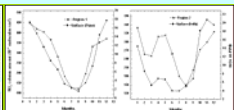


- Vehicle population in India is growing by about 5% per year.
- Energy rates in India experience an annual growth rate of 4-6%.
- Percentage decadal growth in region 1, 2 and 3 is ~25-50% which is high as compared to regions 4 and 5 (10-25%).

Seasonal variation in NO_2 over India observed from the satellite

- Seasonal cycles typically show a NO_2 maximum during winter and summer time, and a minimum during the monsoon season.
- Low NO_2 during monsoon is due to advection of moist clean air mass, heavy precipitation, strong actinic fluxes and enhanced levels of OH radicals.

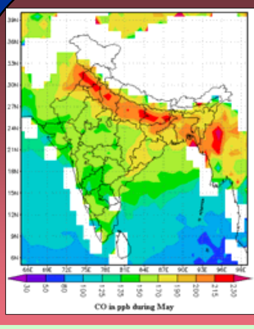




- Satellite observed seasonal variation in the NO_2 is in agreement with the surface measurements demonstrating ability of the satellite to detect pollution within the boundary layer.

(Ghude et al., JGR, 2008)

Carbon monoxide (CO) distribution over the Indian-subcontinent



CO distribution (ppb) at 850 hpa during May observed from the MOPITT measurements.

The major source of CO emission in India is tradition bio-fuel use for domestic purpose (firewood, cow dung, crop residue the main fuels for cooking in rural India), followed by coal (which is used in thermal power plant and industries like, steel, cement etc.) and petrol and diesel consumption.

High CO concentration is observed over the IG region. It can be noticed that the maximum CO emission is from the highly populated states of Uttar Pradesh, Bihar and West Bengal, where nearly 80% of population lives in rural areas and bio-fuel usage through fuel wood burning is expected to be intense.

CO distribution has a close correspondence with the coal and bio-fuel consumption pattern of India.

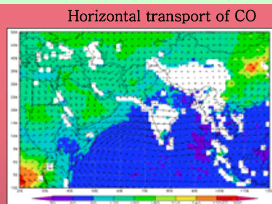
Transport of CO from the Indian-subcontinent

South-west monsoon brings moist clean oceanic air reducing CO levels over much of the Indian region and surrounding ocean (Arabian sea and Bay of Bengal).

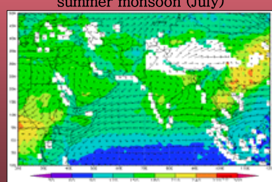
Lower tropospheric path of airflow transports CO from India (Indo-Gangetic and Bombay plume) over the surrounding ocean during north-east monsoon.

Enhanced CO concentration in the mid-troposphere during summer monsoon shows the evidence of convective transport of CO over India.

Horizontal transport of CO

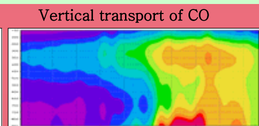


CO (ppb) at 850 hpa during Indian summer monsoon (July)

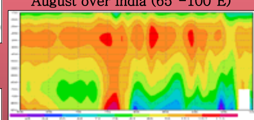


CO (ppb) at 850 hpa during Indian winter monsoon (December)

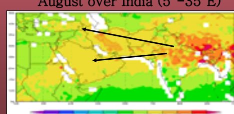
Vertical transport of CO



Pressure latitude cross-section during August over India (65°-100°E)

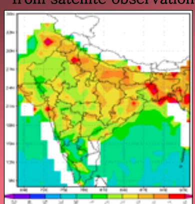


Pressure long. cross-section during August over India (5°-35°E)



High CO concentration in the mid-troposphere and westward transport

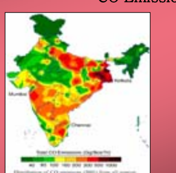
Major CO emission hot-spots from satellite observations



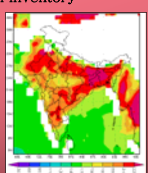
CO emission hot-spots are observation over the densely clustered industrial regions, large thermal power plants and big cities.

CO during September

Comparison of satellite observed CO with CO Emission inventory



CO distribution from emission inventory (*Dalvi et.al., 2006*)



MOPITT CO (ppb) at 850 hpa during March

Conclusions:

Satellite measurements can be used to identify the large emission hotspots (hardest hit regions) in India in order to mitigate the causes of pollution.

Satellite measurements are able to measure the increase of tropospheric NO_2 concentration over different regions of India.

MOPITT CO retrievals can distinguish vertical tropospheric profile over the Indian region and can be employed to study vertical transport phenomena such as convection, and as well as long range transport.

Acknowledgment:

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