Near-Automated Estimate of City Nitrogen Oxides Emissions Applied to South and Southeast Asia

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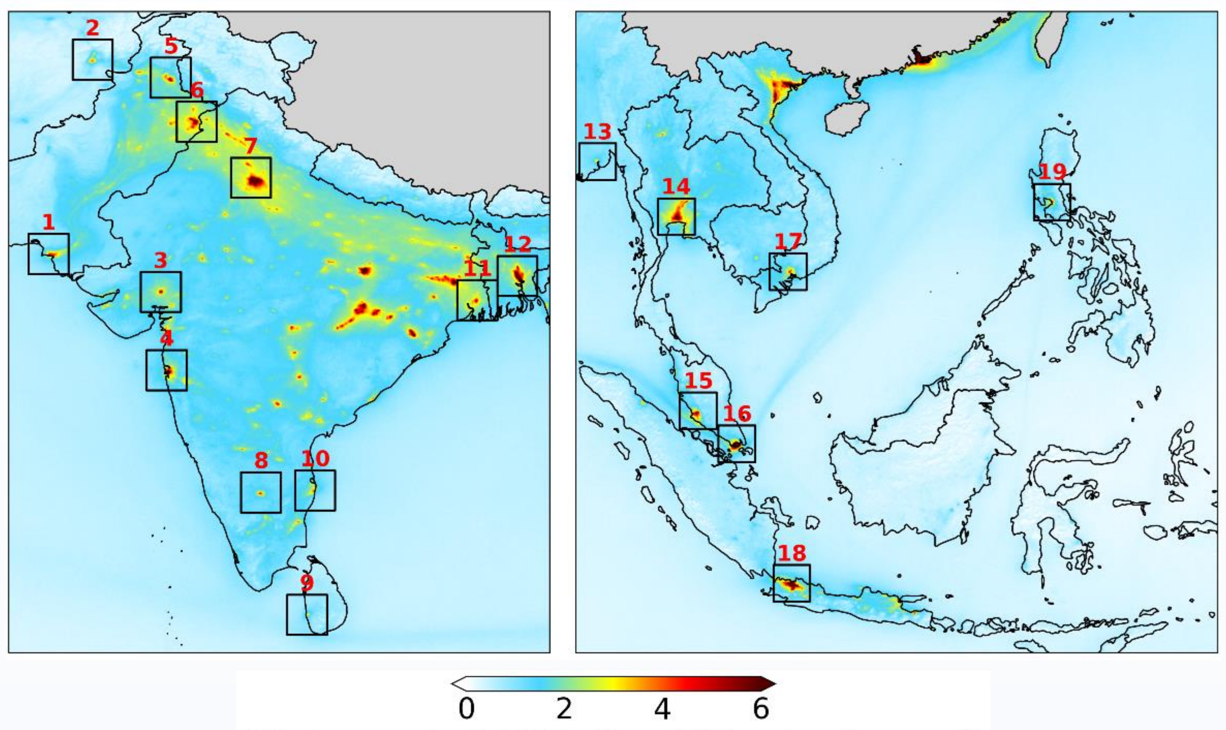
1. Introduction

Cities in South and Southeast Asia are developing rapidly, but lack routine, up-to-date, publicly available inventories of air pollutant precursor emissions such as nitrogen oxides (NO_x). A well-established approach of deriving city NO_x emissions from satellite observations of nitrogen dioxide (NO_2) tropospheric column densities uses wind rotation to align the city plume along a consistent direction and applies a best-fit Gaussian to estimate top-down NO_x emissions. An issue that impacts success of this approach is the manual selection of the sampling area around the city centre. Here, we enhance and automate this approach and use TROPOspheric Monitoring Instrument (TROPOMI) NO_2 observations to derive annual and monthly NO_x emissions over 19 cities in South and Southeast Asia and compare them against bottom-up emissions from the Hemispheric Transport of Air Pollution (HTAP).

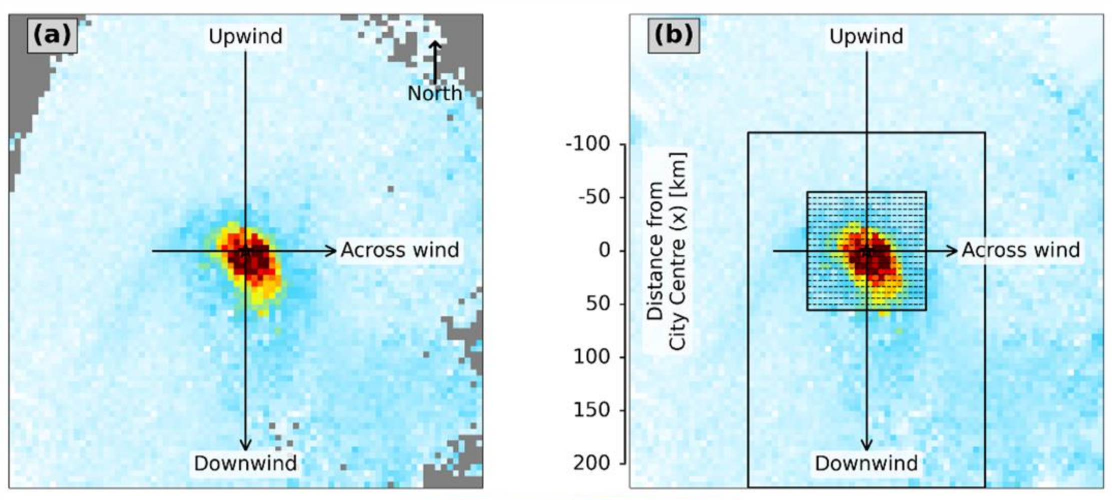
2. Methodology

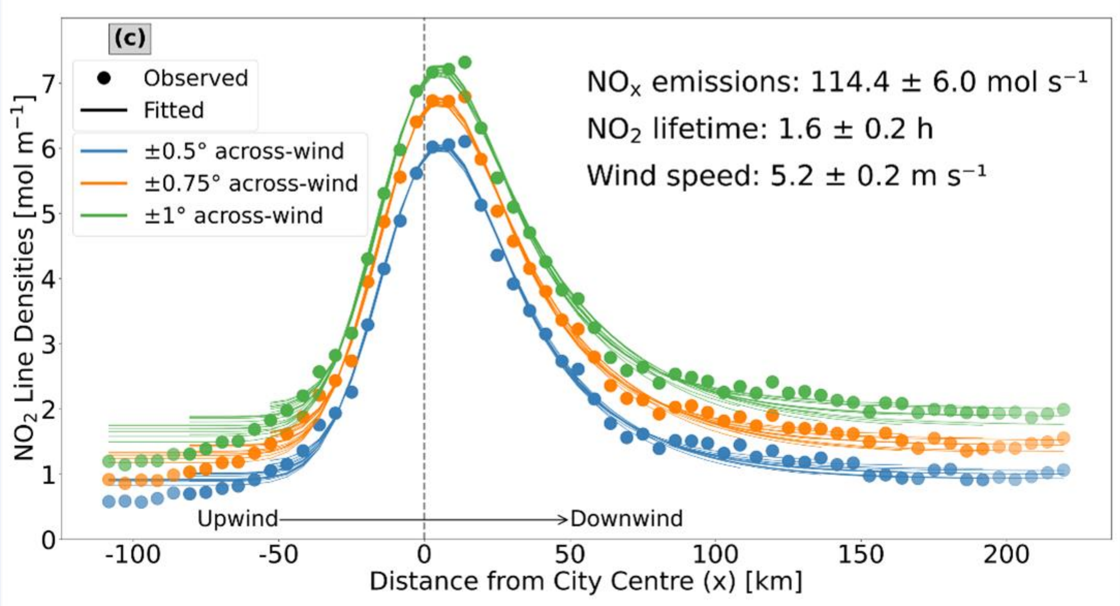
TROPOMI NO_2 and City Selection



Maps show South (left) and Southeast (right) Asia TROPOMI tropospheric NO_2 VCDs oversampled to 0.05° × 0.05° for 2019. The selected cities are: Karachi (1), Islamabad (5), and Lahore (6) in Pakistan; Kabul (2) in Afghanistan; Ahmedabad (3), Mumbai (4), Delhi (7), Bangalore (8), Chennai (10), and Kolkata (11) in India; Colombo (9) in Sri Lanka; Dhaka (12) in Bangladesh; Yangon (13) in Myanmar; Bangkok (14) in Thailand; Kuala Lumpur (15) in Malaysia; the sovereign city Singapore (16); Ho Chi Minh City (17) in Vietnam; Jakarta (18) in Indonesia; and Manila in the Philippines (19).

Wind Rotation and Exponential Modified Gaussian (EMG) Fit





$$F(x|a,x_0,\mu_x,\sigma_x,B) = \frac{a}{2x_0}\exp\left(\frac{\mu_x}{x_0}+\frac{\sigma_x^2}{2x_0^2}-\frac{x}{x_0}\right)\mathrm{erfc}\left(-\frac{1}{\sqrt{2}}\left[\frac{x-\mu_x}{\sigma_x}-\frac{\sigma_x}{x_0}\right]\right)+B \quad (1)$$

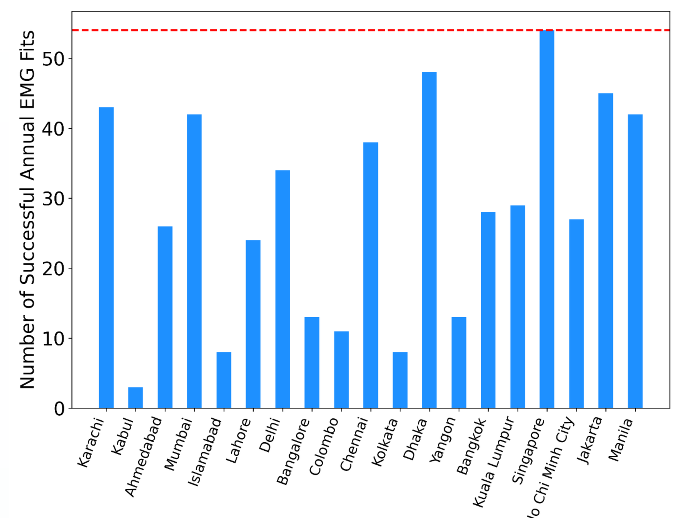
$$\tau_{NO_2} = \frac{x_0}{\omega} \quad (2)$$

$$E_{NO_x} = \gamma \times \frac{a}{\tau_{NO_2}} \quad (3)$$

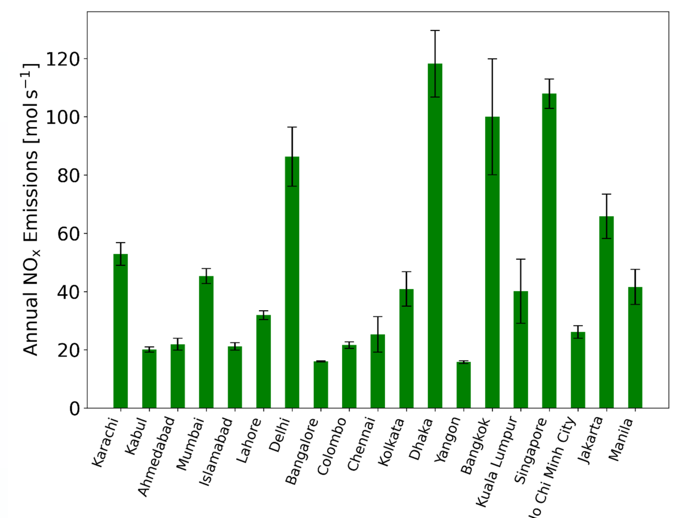
Illustration of major steps in the wind rotation and the Exponential Modified Gaussian (EMG) fit to derive NO_x emissions for Singapore in September 2019. The main steps in each panel are wind rotate and grid windy scene TROPOMI NO_2 pixels to 0.05° × 0.05° (a), fill data gaps (b), and fit the EMG function (Eq. (1)) (solid lines) to observed line densities (filled circles) (c). Black rectangles in (b) show the extent of the largest and smallest sampling areas and the dashed lines in the smallest area show the 0.05° increments used to calculate the line densities in (c). All 54 successful EMG fits, 18 for each across-wind area, are shown in (c). Values in (c) give the mean and standard deviations of the city NO_x emissions (Eq. (3)), effective NO_2 lifetime (Eq. (2)), and ERA5 wind speed below 900 hPa. The R^2 is ≥ 0.98 for all successful fits in (c).

3. Successful EMG Fits, Annual and Monthly NO_x Emissions

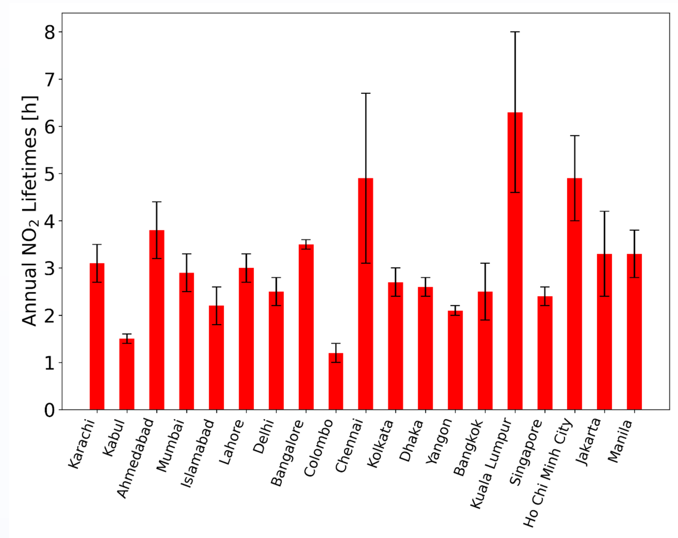
Number of Successful Annual EMG Fits



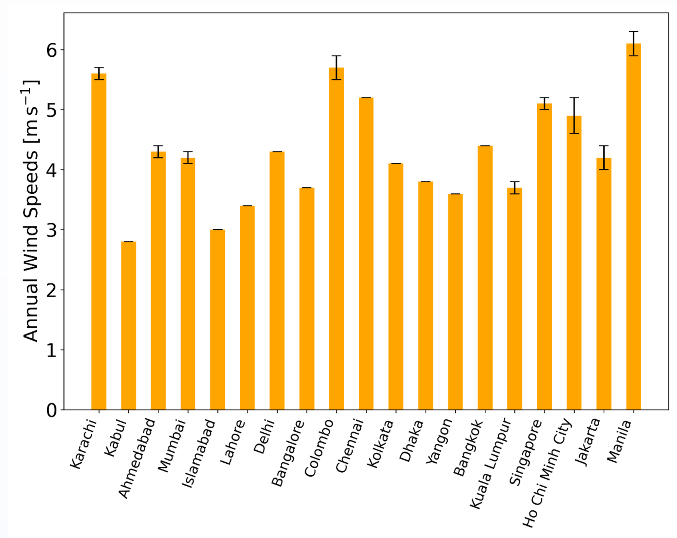
Annual NO_x Emissions with Standard Deviations



Annual Effective NO_2 Lifetimes with Standard Deviations

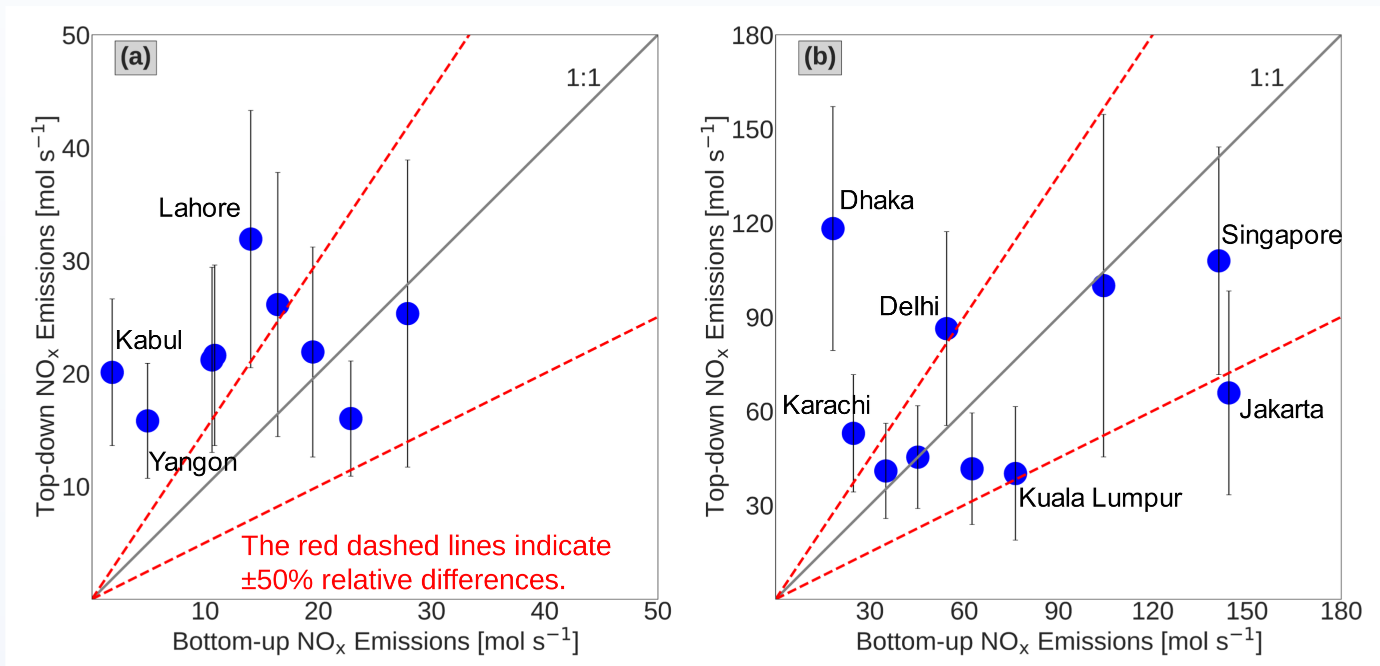


Annual Wind Speeds with Standard Deviations



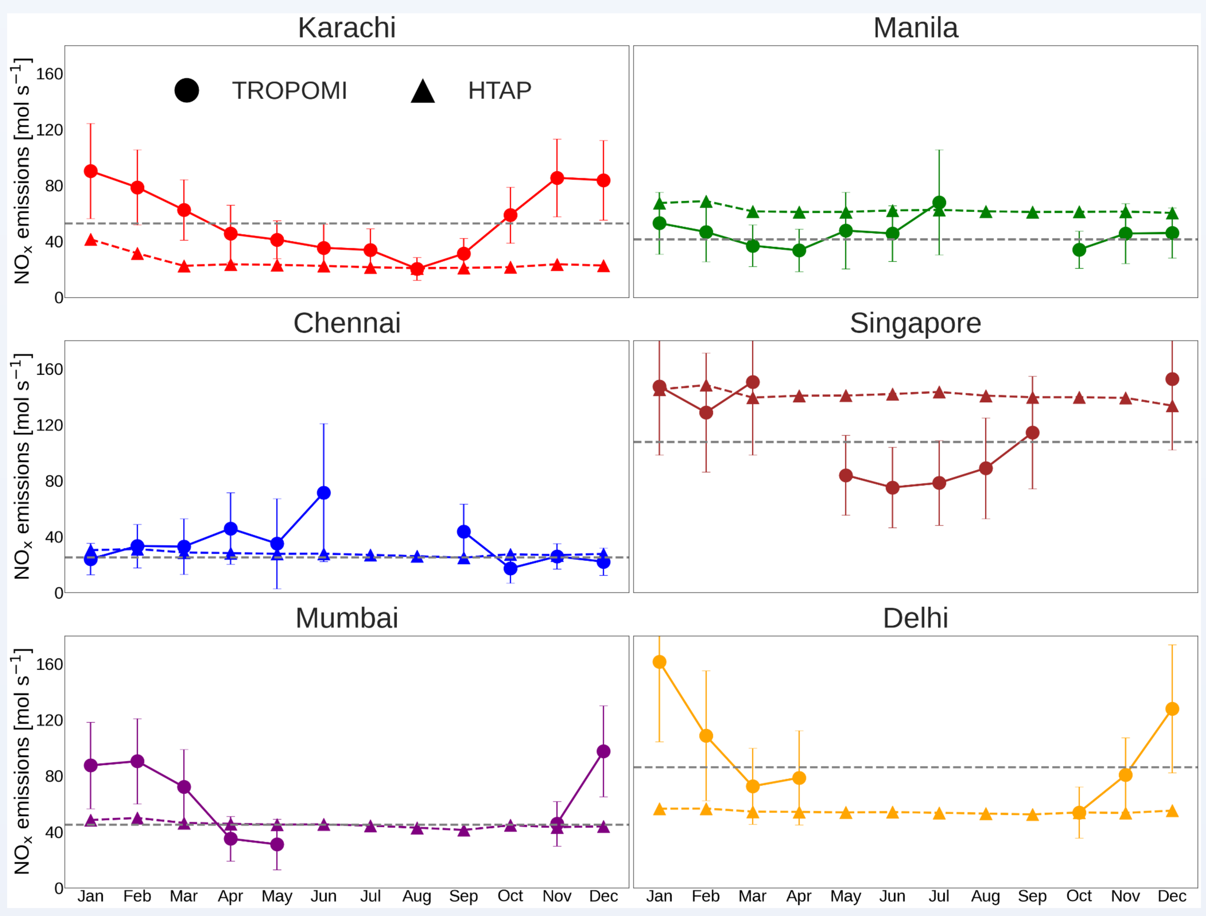
Our method increases success of annual emissions from 40-60% to 100%

Comparison of Annual Top-down and Bottom-up NO_x Emissions from HTAP



The relative difference between our top-down estimates HTAP are < 50% for 9 cities, within 50-100% for 5 cities, and much greater for Karachi (114%), Lahore (127%), Yangon (3.2 times), Dhaka (6.5 times), and Kabul (10-fold).

Monthly Top-down and Bottom-up NO_x emissions



Top-down monthly emissions typically peak in cold season months, while bottom-up emissions lack monthly variability resulting from seasonality in demand for NO_x-producing combustion sources.

4. Conclusions

- Our refined method of deriving city NO_x emissions addresses issues of sampling area selection, automates the applications and improves the success.
- Annual emissions are mostly under 50 mol s^{-1}, with exceptions in Karachi, Delhi, Jakarta, Bangkok, Dhaka, and Singapore. The discrepancies between top-down and bottom-up estimates are less than 50% discrepancy for 9 cities, 50-100% for 5 cities, and much higher for 5 others.
- Top-down monthly emissions reveals monthly variability that is missing from bottom-up emissions.

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