SO_2 emissions and lifetimes derived from TROPOMI observations over India using a flux-divergence method

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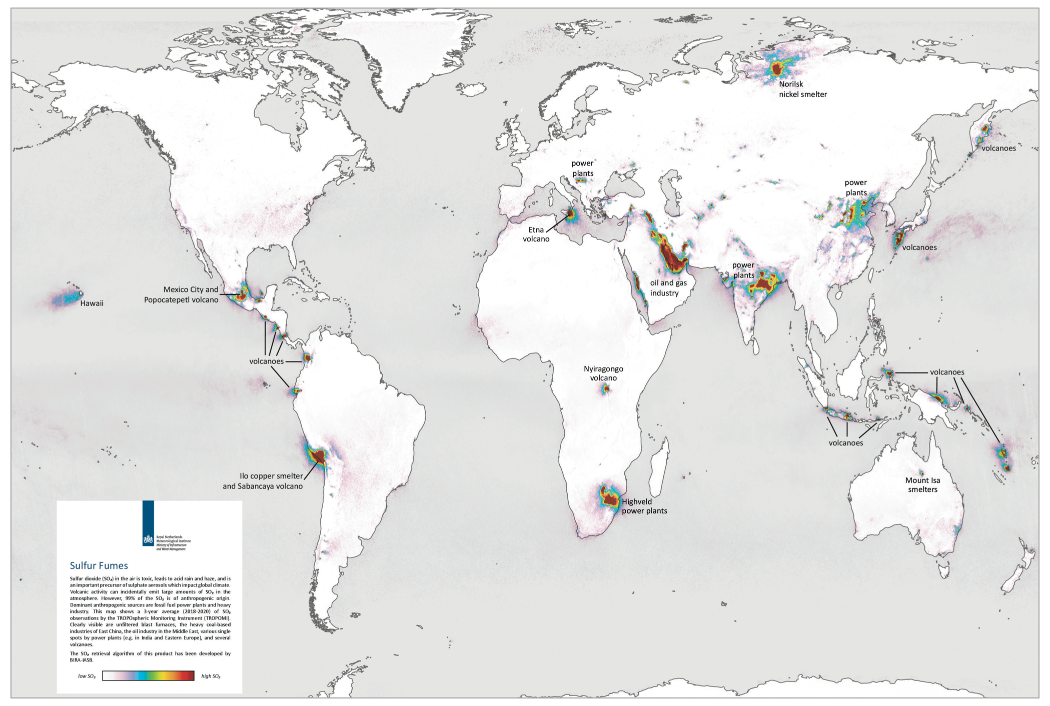
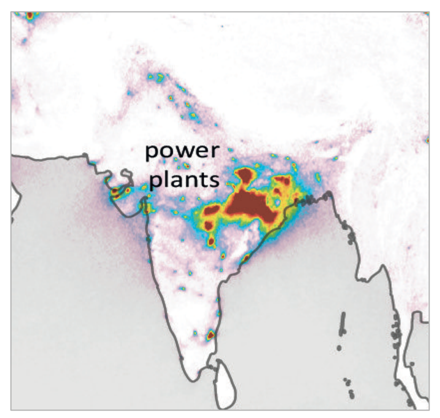
1. Introduction

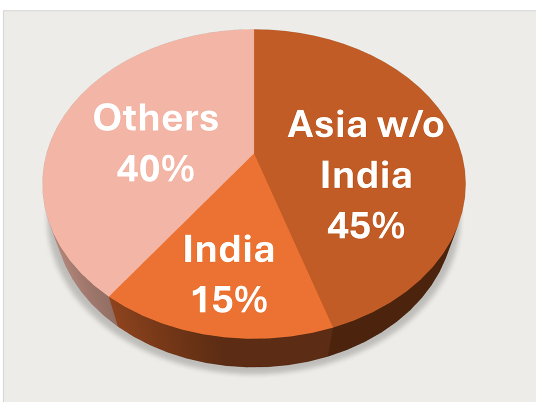
1.1 SO_2 major sources (TROPOMI)



- Global SO_2 emissions: decreased by 31% between 1990-2015
- East Asia SO_2 emissions : increased by 70% in 1990-2005 and continued decreasing thereafter

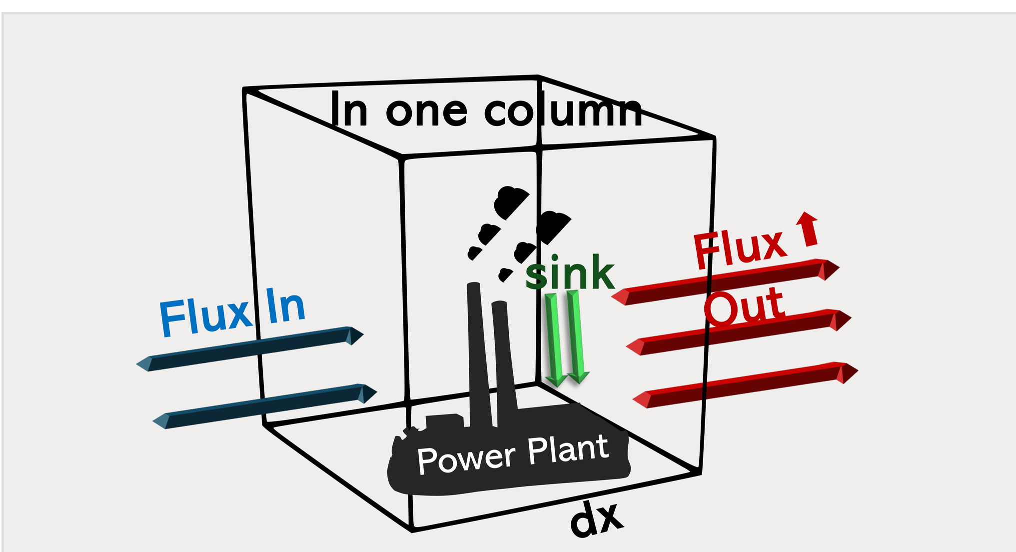
1.2 Indian anthropogenic emissions





- India became the 1st SO_2 emitter after 2015
- India heavily relies on the coal-based thermal power plants to meet the growing energy demands -> large amount of SO_2 emissions
- Fast-paced changes in economy and environmental regulations will lead to unforeseen emission changes in India-> requires of timely and accurate SO_2 emissions

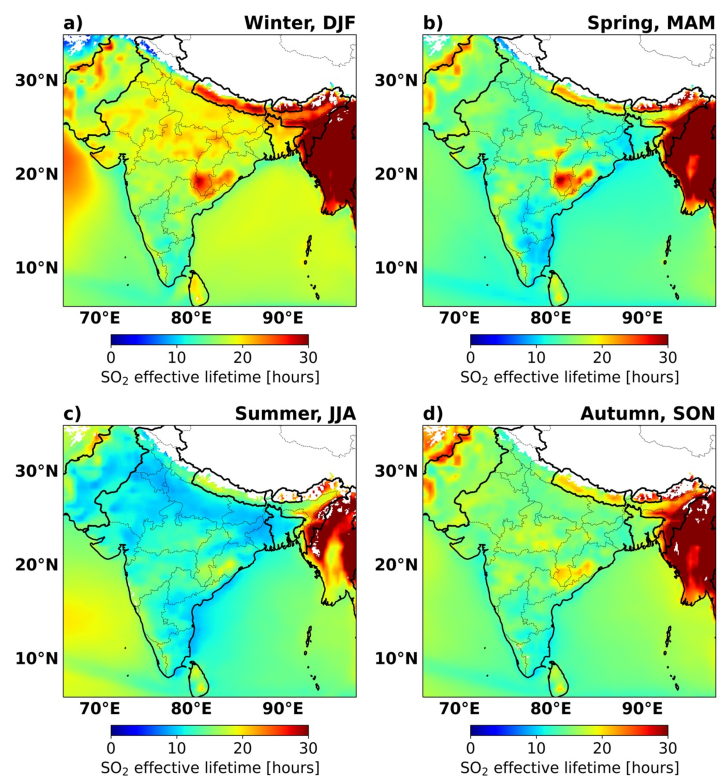
1.3 Flux-divergence method



Emissions = Divergence + Sink

2. Methodology

2.1 SO_2 Lifetime in India

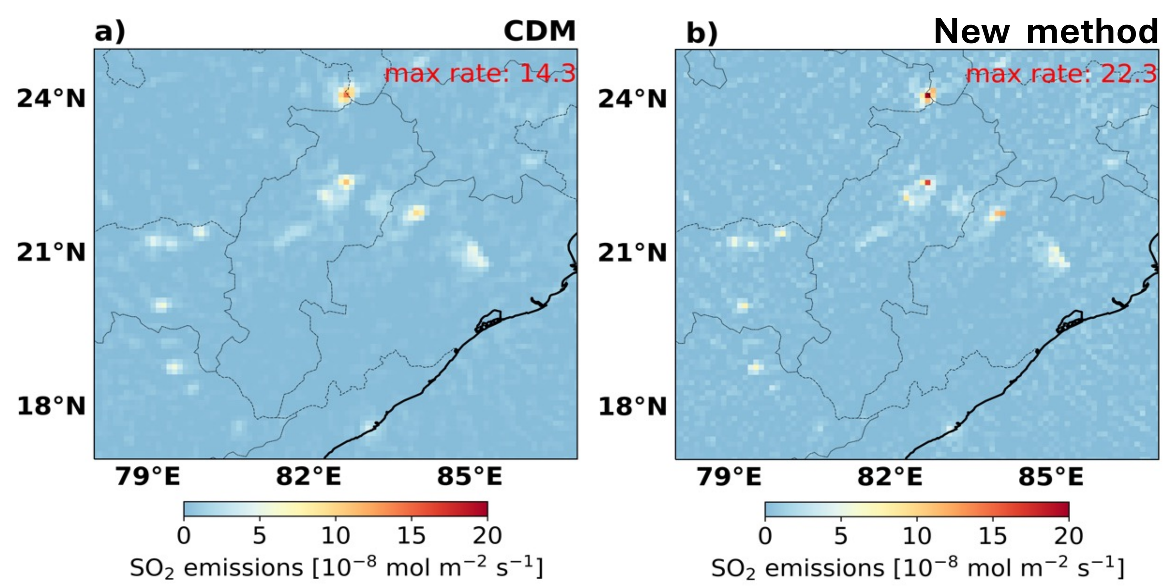


- The SO_2 seasonal mean lifetimes averaged over India in winter, spring, summer, and autumn are 19, 15, 12, and 16 hours.

- $Sink = \frac{V_{SO_2}}{\tau}$
- $\frac{1}{\tau} = \frac{1}{\tau_c} + \frac{1}{\tau_d}$
- $\tau_c = \frac{1}{k[OH]}$
- $\tau_d = \frac{PBL}{0.4}$

- V_{SO_2}: SO_2 satellite observations from TROPOMI SO_2 Level-2 COBRA dataset (from December 2018 to November 2023)
- τ: SO_2 effective lifetime; τ_c: SO_2 chemical lifetime; τ_d: SO_2 dry deposition lifetime
- [OH]: OH climatology derived from the CAMS atmospheric composition forecast data; k: chemical constant rate
- 0.4: dry deposition velocity derived from the field measurements (unit: cm s-1)

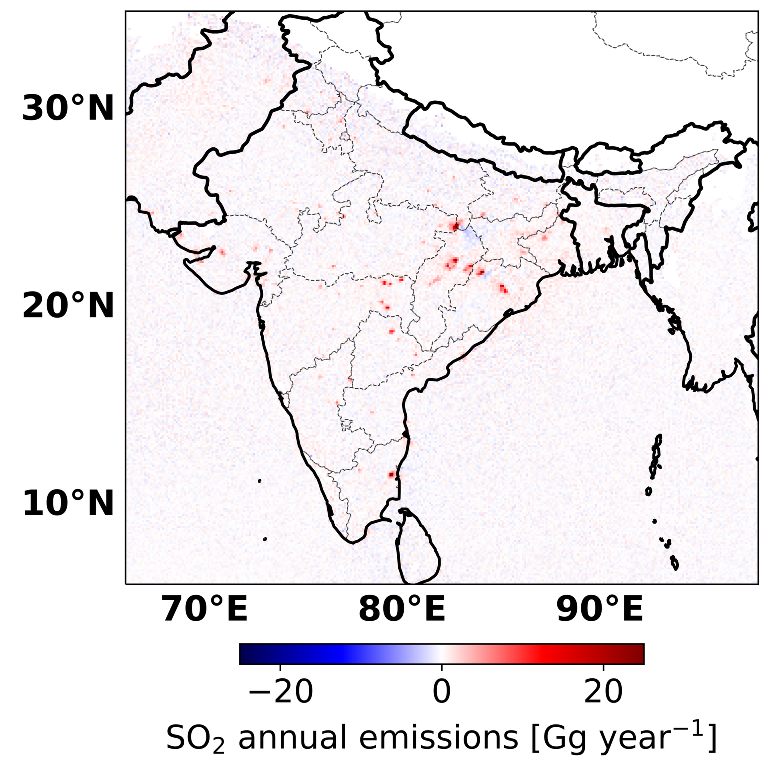
2.2 Improve the Classic Divergence Method (CDM)



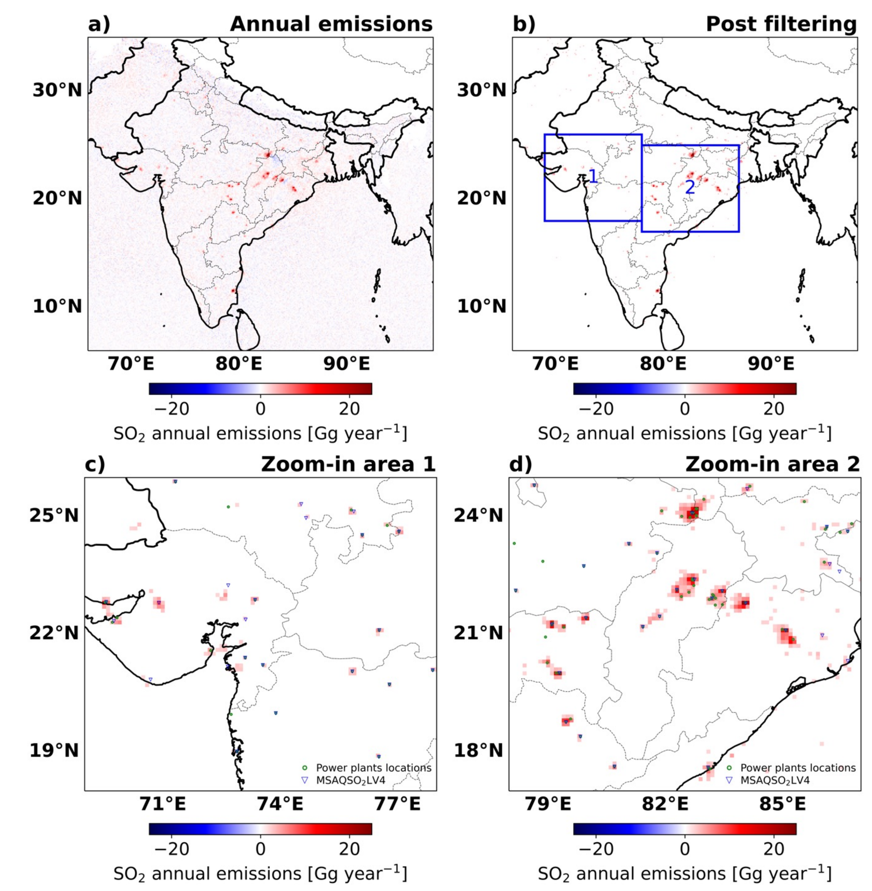
- CDM: $D_{x(i)} = \frac{\vec{F}_{x(i+1)} - \vec{F}_{x(i-1)}}{2\Delta x}$,
  - where $D_{x(i)}$ represents the divergence in the center of grid cell i calculated from x direction. $\vec{F}_{x(i)}$ denotes the SO_2 flux in the center of grid cell i along x direction
  - The divergence in the center of grid cell i is equal to the linear interpolation of the divergence at the edges of the grid cell i
- New method: Allocate all of the edge divergence to the grid cell with the larger SO_2 VCD.

3. Results

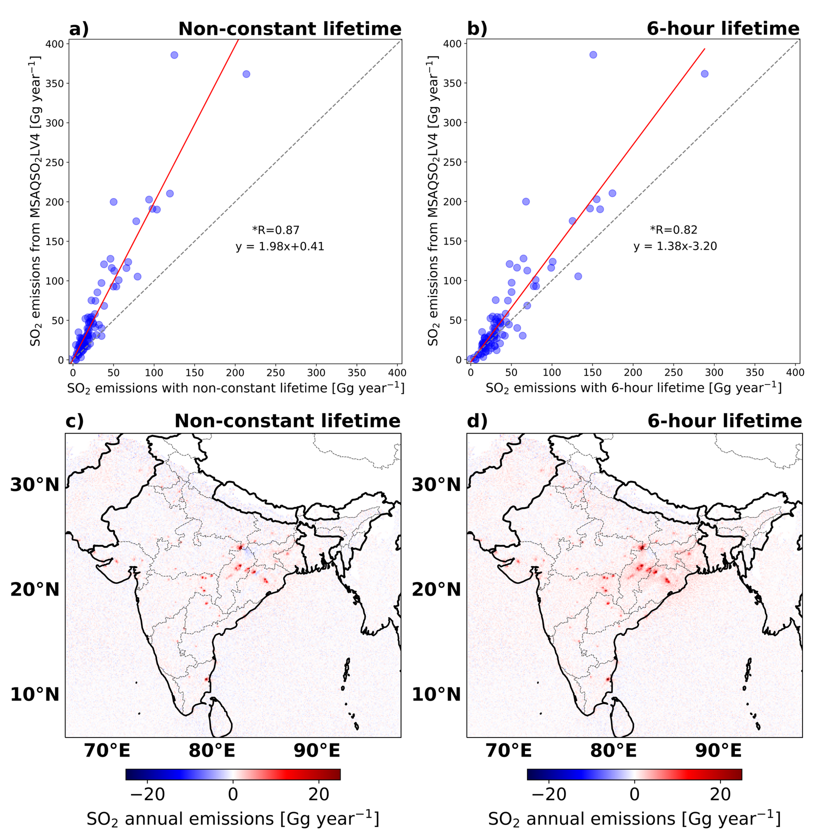
3.1 SO_2 emissions



- The annual mean emissions for the whole of India from December 2018 to November 2023 are approximate 5.7, 4.2, 5.1 and 5.1, 5.7 Tg year-1, with the 5-year averaged SO_2 emissions being 5.2 Tg year-1.
- The Indian SO_2 emissions show a seasonality: the emissions in winter are 0.50 Tg month-1, in spring 0.57 Tg month-1, in summer 0.25 Tg month-1 and in autumn 0.41 Tg month-1.
- A clean ocean region which is evenly distributed with the noise is selected to detect the emission detect limitation. The 4σ, about 2 Gg year-1, is set as the detect limitation.



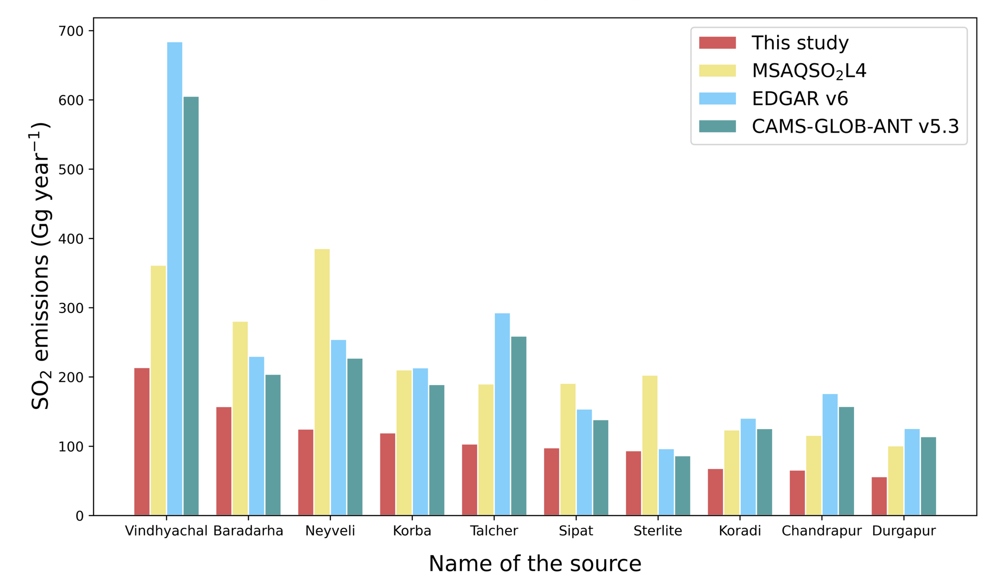
3.2 SO_2 emissions comparison



a) Comparison to the MSAQSO2L4 92 large point-source emissions: total emissions of 2.9 Tg year-1 is notably lower than 5.2 Tg year-1 in MSAQSO2L4.

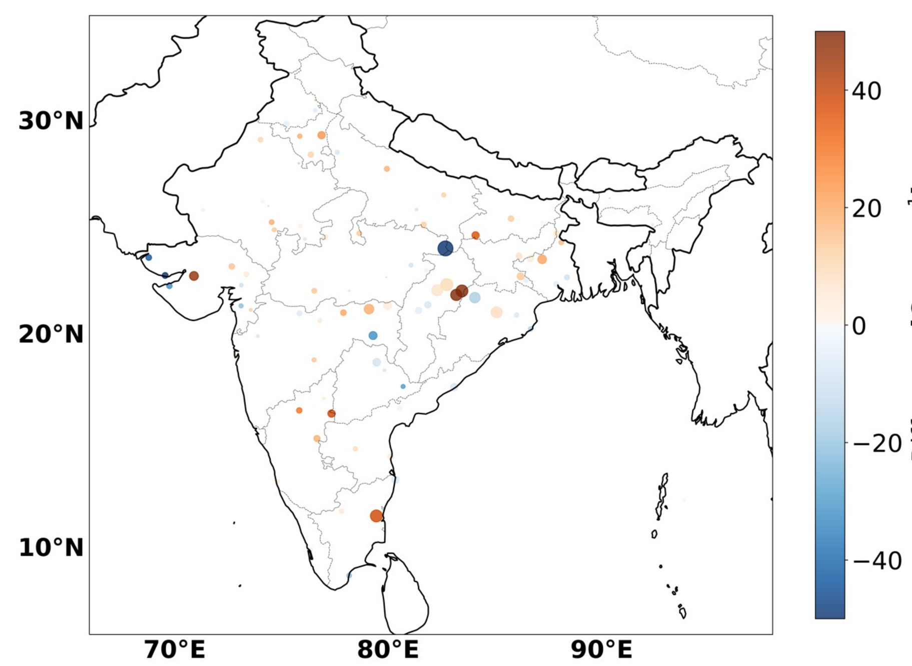
d) If a fixed 6-hour lifetime is used, the emission map shows a spreading effect. A overall positive bias occur in the emission map.

Comparison of top 10 point sources



- Our top 10 sources are associated with thermal power stations, emitting in total 1.1 Tg year-1, which accounts for 21% of all SO_2 emissions in India. The emissions from our top 10 sources are lower than those reported by the other inventories

3.3 SO_2 emission changes between 2019 and 2023



- The total point source emissions in India are estimated to be 2.8 Tg year-1 in 2019 and 3.0 Tg year-1 in 2023.
- The emissions of Vindhyachal, the point source showing the largest decrease, were reduced by 17%, which is about 43 Gg year-1.
- The largest increasing emitter, Baradarha, increased over 75%, which is in total 107 Gg year-1 of SO_2 emissions.

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