High resolution quantification of SO_2 emissions over India based on TROPOMI observations

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S1. The Gaussian-shaped function to derive the spreading kernel *B*

$$f(x) = e^{-\frac{x^2}{2\cdot\sigma^2}} \tag{S1}$$

with σ = 1.82. The variable *x* is the distance from the center of point source grid cell, represented in unis of grid cells. Specifically, when *x* = 0, it refers to the grid cell containing the point source itself. When *x* = 1, it refers to the distance to directly adjacent neighboring grid cells. When $x = \sqrt{2}$ (approximately 1.414), it refers to the distance to diagonally adjacent grid cells. Additional values of *x* represent distances to more distant grid cells, calculated according to their relative positions.

The spreading pattern $\boldsymbol{B'}$ is defined within a 9 × 9 grid cell area centered on the grid cell containing the point source and is derived from the Eq. S1. The spreading kernel $\boldsymbol{B}$, which is used to calculate the sharpening kernel, is the normalized form of $\boldsymbol{B'}$ and can be expressed as:

$$\boldsymbol{B} = \frac{\boldsymbol{B'}}{\sum_{i=-4}^{4}\sum_{i=-4}^{4}\boldsymbol{B'}_{ij}} \tag{S2}$$

S2. The spreading pattern derived from the model-based SO_2 emissions

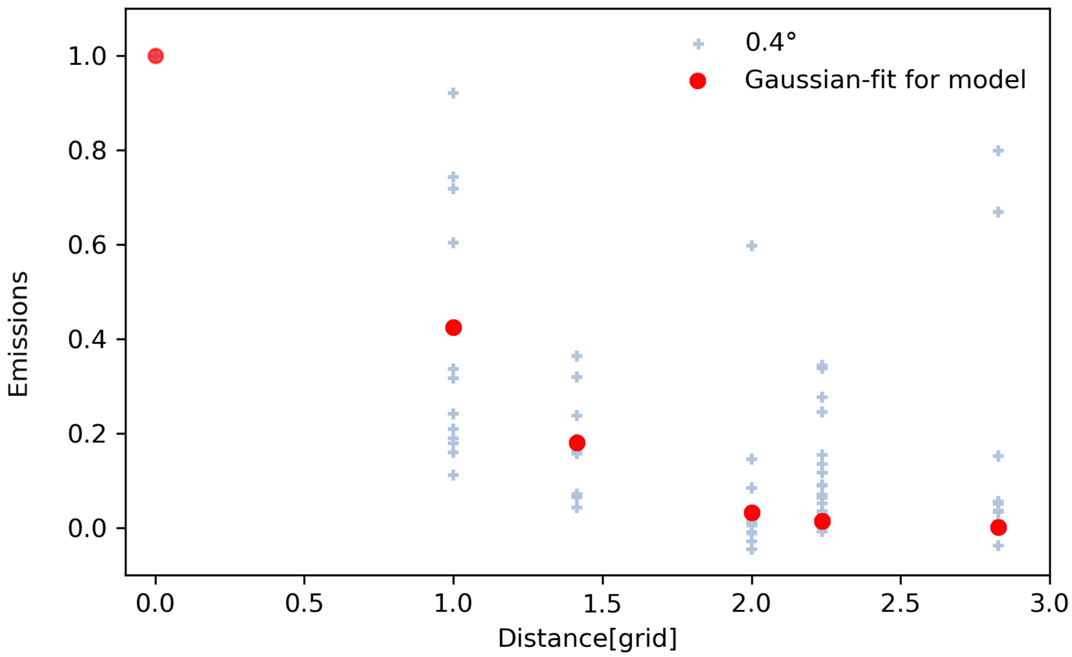

Figure S1. Variation of normalized SO_2 emissions with distance from the point source location, and the corresponding Gaussian-shaped fitting function with the sigma = 0.67. This emission is derived from the annual mean CAMS model results (0.4° × 0.4°). To avoid interference from nearby sources, we selected one isolated point source for this analysis. The point at (0,1) represents the location of the point emissions decrease to near zero within about two grid cells, so we define a 5 × 5 grid cell area centered on the point source as the emission spreading region.

S3. Point source improvement after deconvolution.

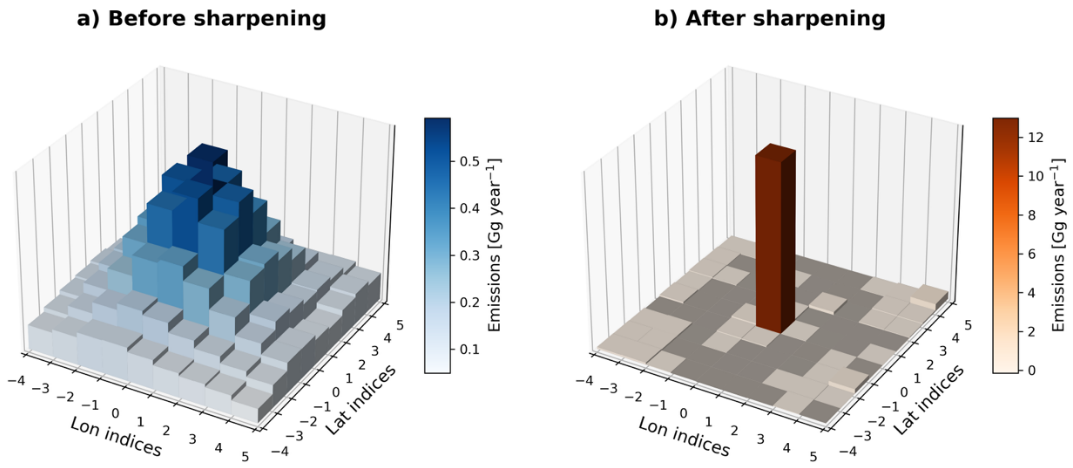

Figure S2. The SO_2 emission distribution a) before sharpening and b) after sharpening centered on a point source within a 9 × 9 grid cell area. This figure is based on the average of 79 selected point sources (See Table S1). The emissions before sharpening follows a 2D Gaussian pattern. The emission after sharpening is more concrete at the point source location and is enhanced approximately 20 times compared to the unsharpened case.

S4. Selected SO_2 point sources in India

Table S1. Locations of selected SO_2 point source location used in Fig. S2 and Fig. 8

Index	**Name**	**Lat**	**Lon**
1	Bara	25.19617	81.65946
2	Kalalgaon	25.239	87.266
3	Chanderia	24.962393	74.66293
4	Chandrapur	20.007187	79.28928
5	Raichur	16.35329	77.34408
6	Rosa	27.8186	79.9374
7	Baradarha	21.911436	83.188866
8	Tirora	21.412502	79.96731
9	Raghunathpur	23.62191	86.660706
10	Wanakbori	22.875216	73.36176
11	Ramagundam	18.75453	79.459694
12	Vindhyachal	24.09	82.68
13	Rayala Seema	14.70275	78.45775
14	Sipat	22.1316	82.292
15	Laharpur	23.06633	81.78591
16	Ukai	21.2093	73.5574
17	Paras	20.714735	76.79482
18	Chelpur	18.38351	79.8265
19	Dadri	28.598288	77.61014
20	Koradi	21.247835	79.1
21	Jhalawar	24.52953	76.0986
22	Tamnar	22.098747	83.45131
23	Talwandi Sabo	29.92419	75.23728
24	Farakka	24.773598	87.89403
25	Simhadri	17.595188	83.089905
26	Vijayawada	16.599628	80.53608

27	Talcher	21.095535	85.075615
28	Nabinagar	24.70508	84.08919
29	Nandgaonpeth	21.07823	77.90088
30	Mettur	11.772061	77.814865
31	Surat	21.397985	73.107414
32	Tanda	26.59359	82.59682
33	Raikheda	21.449919	81.85247
34	Unchahar	25.913	81.327
35	Lalitpur	24.79718	78.64634
36	Dongaliya	22.102777	76.53611
37	Kudgi	16.5	75.833336
38	Barrackpore	22.732	88.37
39	Kothagudem	17.621553	80.69661
40	Kutch	23.663885	68.78404
41	Bhilai	21.18372	81.42307
42	Chowki Motipura	24.62	77.04
43	Gandhi Nagar	23.244513	72.67438
44	Birsinghpur	23.305834	81.065
45	Neyveli	11.554936	79.4439
46	Nasik	19.981657	73.88958
47	Sagardighi	24.37193	88.1041
48	Suratgarh	29.182514	74.019485
49	Mundra	22.822779	69.55278
50	Bhadresh	25.89213	71.32658
51	Sterlite	21.78498	84.0553
52	Kota	25.1299	75.88405
53	Nelatur	14.32611	80.12156
54	Tuticorin	8.763055	78.17149
55	Bhusawal	21.048285	75.84586
56	Satpura	22.111746	78.172066

57	Salakati	26.4448	90.36323
58	Morbi	22.799524	70.90123
59	Gandhi Nagar	25.318169	74.54007
60	Paricha	25.5127	78.7581
61	Chandrapura	23.737535	86.12696
62	Trombay	19.0033	72.897
63	Durgapur	23.577469	87.209145
64	Parli	18.86809	76.52539
65	Torangallu	15.183938	76.66217
66	Barh	25.4865	85.7452
67	Kolaghat	22.414848	87.87327
68	Essar	22.333313	69.7524
69	Indira Gandhi STPP	28.48502	76.37542
70	Gujarat	22.37142	73.11951
71	Tata	22.785	86.2
72	Duburi	20.96675	86.012405
73	North Chennai	13.25	80.33
74	Khedar	29.34782	75.85842
75	Panipat	29.395813	76.8783
76	Jaigarh	17.297	73.212
77	Rajpura	30.557	76.577
78	Hazira	21.165	72.661
79	Korba	22.3933	82.74253

S5. Noise level

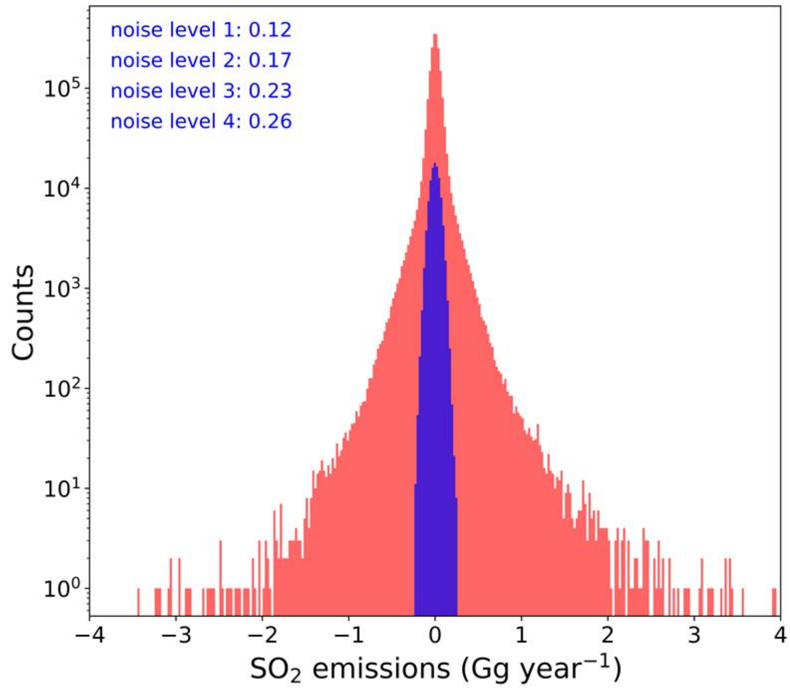

Figure S3. Histogram of the frequency of SO_2 emissions. The red bars represent the frequency of SO_2 emissions within the simulation domain. The blue bars denote the frequency of SO_2 emissions (or the noise) in the selected clean oceanic region (latitude: 5°N-18°N; longitude: 85°E- 90°E). The emissions signal within this clean region are identified as noise. The frequency distribution of noise within the selected clean region approximates a normal distribution with σ = 0.06 Gg year^{-1}. Based on our tests, we set the detection threshold as three times σ (about 0.17 Gg year^{-1} per grid cell). The noise level 0.17 Gg year^{-1} is derived from the unsharpened emissions. The noise level after sharpening is enhanced by approximately 20 times, reaching 3.4 Gg year^{-1}. See more information in the study from Chen et al. (2025).

Reference

Chen, Y., van der A, R. J., Ding, J., Eskes, H., Williams, J. E., Theys, N., Tsikerdekis, A., and Levelt, P. F.: SO2 emissions derived from TROPOMI observations over India using a flux-divergence method with variable lifetimes, Atmos. Chem. Phys., 25, 1851-1868, 10.5194/acp-25-1851-2025, 2025.