Supplementary

Table S1. Prior and posterior emissions with the sensitivity of posterior emissions to observations (Section 2.8) for the 17 states in India with prior emissions above 0.6 Tg yr^{-1}. The values in the parenthesis represent the ensemble range derived from 30 ensemble members.

States	Prior emissions (Tg yr^{-1})	Posterior emissions (Tg yr^{-1})	Sensitivity
Haryana	0.7	0.7 (0.6 – 0.8)	0.5 (0.3 – 0.7)
Jharkhand	1.1	0.8 (0.7 – 1.2)	0.4 (0.2 – 0.5)
Punjab	1.2	1.1 (1.0 – 1.3)	0.7 (0.4 – 0.8)
Telangana	1.2	1.5 (1.3 – 1.7)	0.5 (0.3 – 0.7)
Chhattisgarh	1.2	0.8 (0.7 – 1.1)	0.4 (0.3– 0.6)
Assam	1.4	1.7 (1.5 – 1.7)	0.6 (0.4 – 0.7)
Andhra Pradesh	1.5	2.3 (2.0 – 3.2)	0.4 (0.2 – 0.6)
Karnataka	1.5	2.2 (1.8 – 2.5)	0.4 (0.2- 0.5)
Gujarat	1.6	2.4 (2.1 – 3.9)	0.4 (0.3 – 0.6)
Tamil Nadu	1.7	2.0 (1.8 – 4.2)	0.3 (0.1 – 0.4)
Odisha	2.0	1.0 (0.7 – 1.4)	0.4 (0.2 – 0.4)
Bihar	2.0	1.9 (1.7 – 2.0)	0.7 (0.5 – 0.8)
West Bengal	2.3	2.2 (2.0 – 2.4)	0.6 (0.4 – 0.7)
Rajasthan	2.4	1.3 (1.1 – 1.6)	0.4 (0.3 – 0.5)
Maharashtra	2.6	2.6 (2.3 – 2.8)	0.5 (0.4 – 0.6)
Madhya Pradesh	2.7	2.4 (2.3 – 3.1)	0.4 (0.3 - 0.6)
Uttar Pradesh	4.3	4.9 (4.4 – 5.2)	0.8 (0.6 - 0.9)

Table S2. Prior and posterior total emissions with the sensitivity of posterior emissions to observations (Section 2.8) for 14 cities in India. The values in parentheses represent the ensemble range.

City	Prior emissions (tons/hr)	Posterior emissions (tons/hr)	Sensitivity
Jaipur	7.2	3.9 (3.2 – 4.8)	0.1 (0.1 – 0.3)
Pune	9.5	9.8 (8.8 – 11.5)	0.3 (0.1 – 0.5)
Vadodara	10.4	13.9 (10.9 – 19.6)	0.3 (0.1– 0.6)
Bangalore	12.1	17.6 (14.5 – 23.6)	0.3 (0.1 – 0.5)
Surat	13.8	14.1 (13.7 – 16.3)	0.3 (0.1– 0.5)
Chennai	14.4	43.6 (22.4 – 60.2)	0.3 (0.1 – 0.4)
Prayagraj	16.3	22.6 (17.8 – 25.7)	0.4 (0.2 – 0.6)
Hyderabad	18.2	23.4 (20.5 – 31.1)	0.3 (0.2 – 0.5)
Lucknow	18.5	27.7 (24.1 – 33.0)	0.5 (0.3 – 0.7)
Ludhiana	19.0	17.7 (16.2 –22.8)	0.5 (0.2 – 0.7)
Ahmedabad	22.4	28.5 (24.2 –32.6)	0.5 (0.3– 0.7)
Mumbai	27.9	30.6 (28.8 –36.1)	0.5 (0.3– 0.7)
Delhi	29.5	40.8 (35.5 – 48.6)	0.6 (0.4 – 0.8)
Kolkata	30.1	43.3 (33.3 – 53.0)	0.5 (0.2 – 0.8)

Table S3. Landfill emissions in 14 Indian cities based on GHGSat adapted from Dogniaux et al. (2024), EDGAR (sum of the 9 grid cells around the landfill), and posterior emissions (same area). The values in parentheses represent the ensemble range. A 'x' means no observation performed.

City	GHGSat (tons/hr)	EDGAR (tons/hr)	Posterior (tons/hr)
Jaipur	x	0.4	0.3 (0.2 – 0.3)
Prayagraj	x	0.5	0.7 (0.5 – 0.8)
Bangalore	x	0.8	1.2 (1.0 – 1.9)
Ludhiana	0.6 ± 0.3	0.4	0.7 (0.6 – 0.8)
Pune	0.8 ± 0.1	0.5	1.1 (1.0 – 1.8)
Vadodara	0.8 ± 0.1	0.3	1.4 (1.1 – 2.4)
Surat	2.9 ± 0.4	0.4	3.0 (2.9 – 3.6)
Lucknow	2.2 ± 0.4	1.5	4.3 (3.4 – 5.0)
Kolkata	1.8 ± 0.4	0.7	3.8 (2.7 – 4.4)
Ahmedabad	3.6 ± 0.4	0.6	6.0 (4.9 – 8.8)
Delhi	7.5 ± 1.0	1.7	9.4 (8.4 – 11.0)
Mumbai	9.4 ± 1.5	0.6	14.2 (13.4 – 17.3)
Hyderabad	6.9 ± 1.0	1.4	9.9 (7.9 – 14.0)
Chennai	5.3 ± 1.3	0.6	23.9 (9.2 – 33.9)

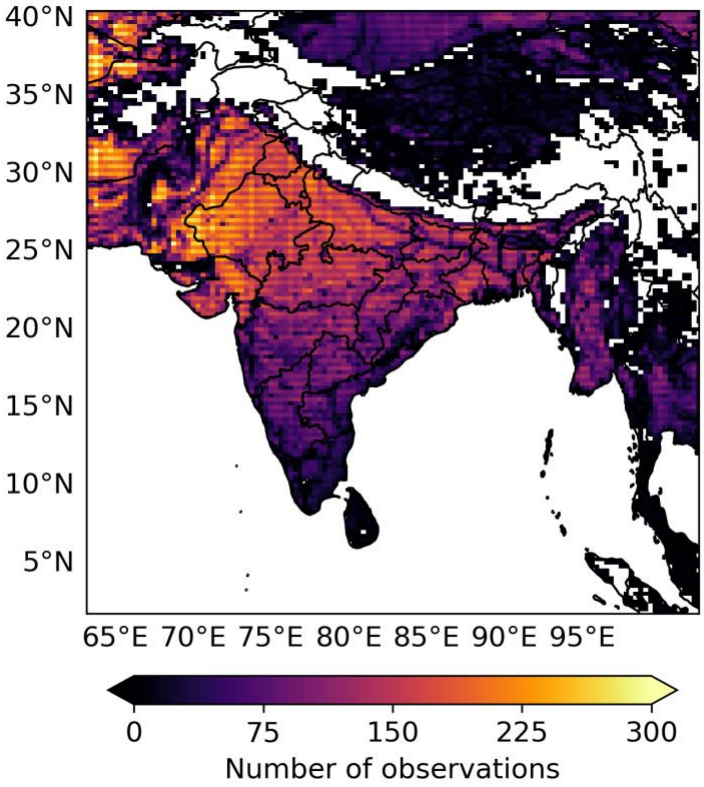

Figure S1. Number of TROPOMI observations gridded at 0.25° x 0.3125° resolution over India in 2021. Borders are taken from Natural Earth (https://www.naturalearthdata.com/about/map-update-committee/) that provides de facto administrative boundaries.

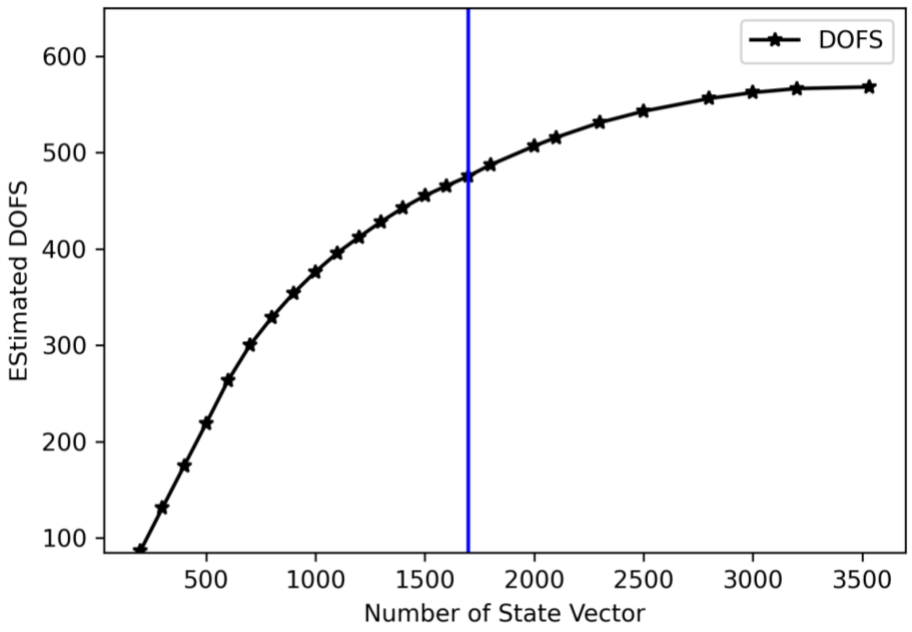

Figure S2. Estimated Degrees of Freedom for Signal (DOFS) as a function of the number of state vector elements used in the inversion. The blue line indicates the number of elements used in the final inversion.

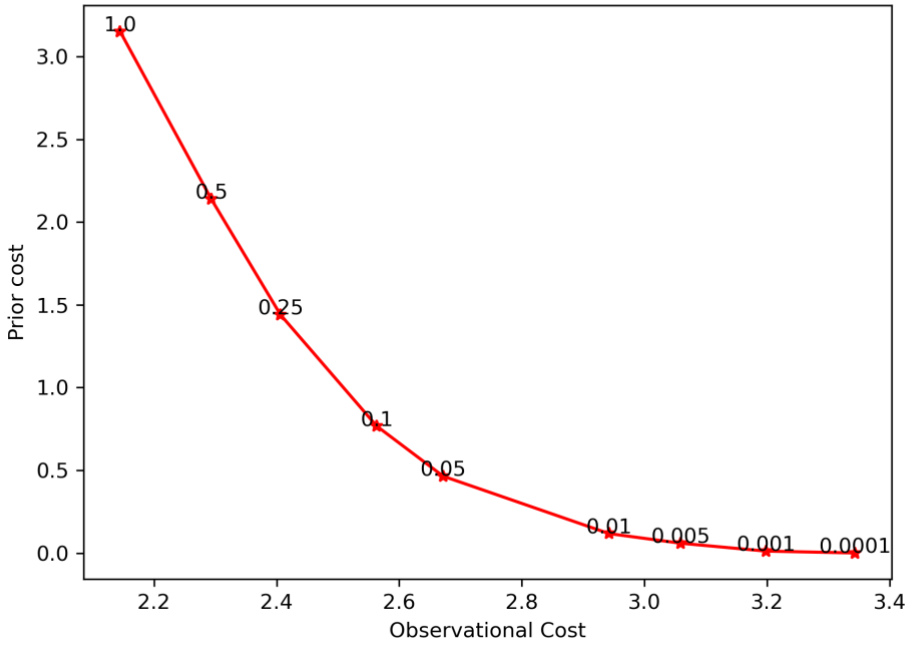

Figure S3. L-curve analysis to estimate the suitable gamma value (γ) for the inversion process. The curve starts to decrease gradually from γ = 0.1 and this value is selected for the base inversion.

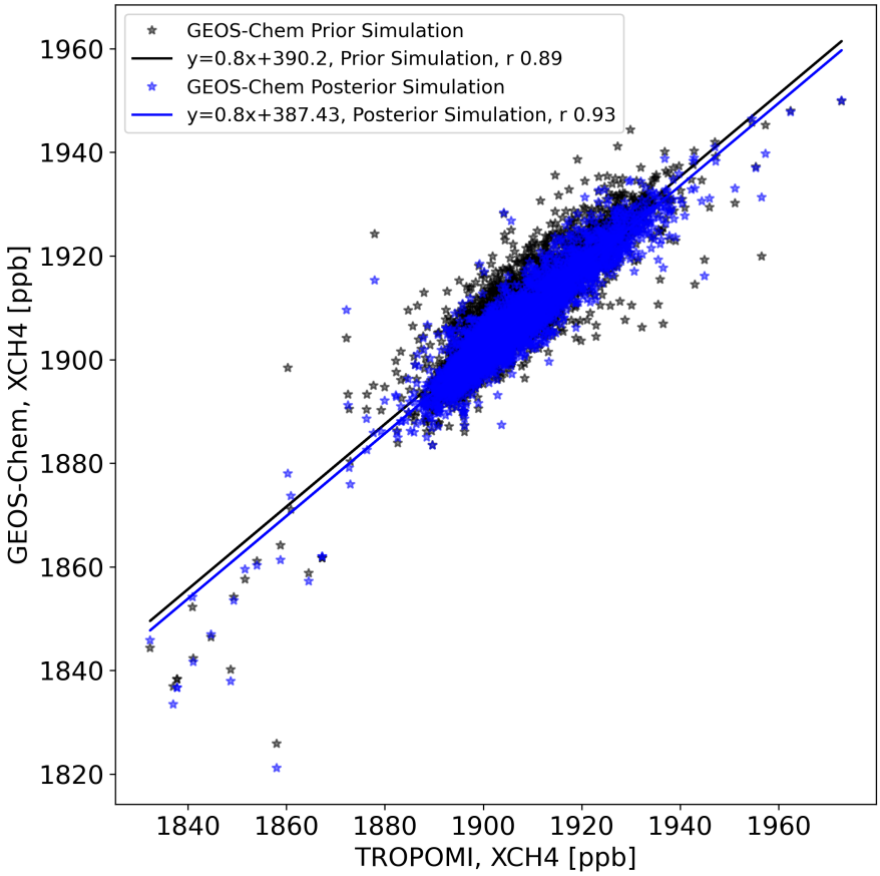

Figure S4. Correlation between TROPOMI and GEOS-Chem derived total methane column mixing ratios using prior and posterior simulations for 2021 over India. The figure also shows linear regressions for both simulations.

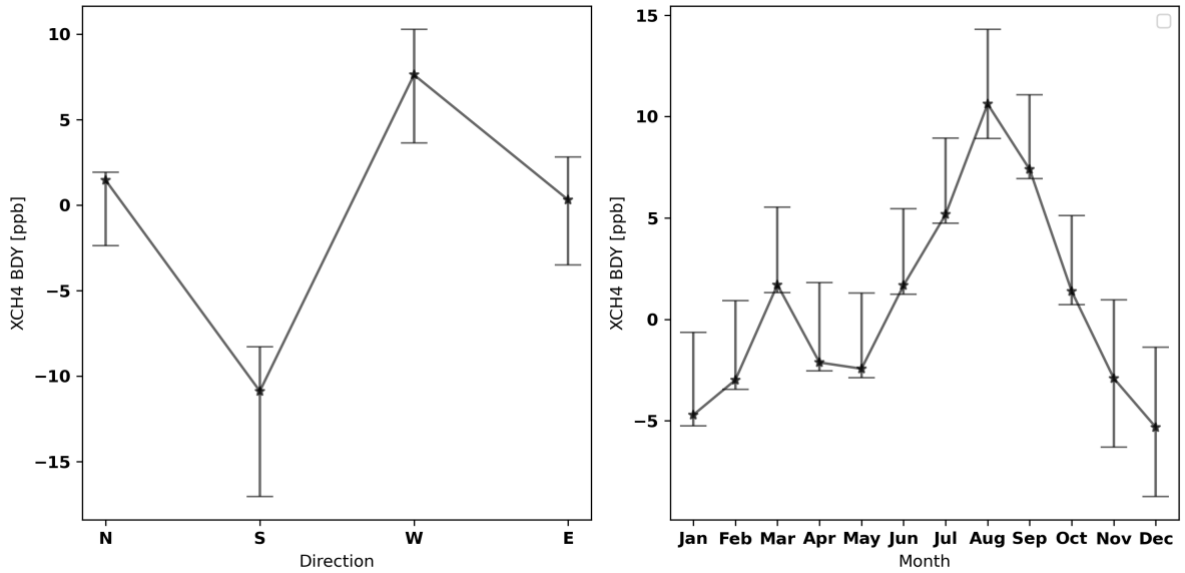

Figure S5. Absolute boundary condition bias corrections at the Northern, Southern, Western, and Eastern boundaries of the domain (left) and monthly domain-level boundary condition corrections (right).

Figure S6. The location and names of the states and union territory of India. Thick lines show de facto borders from Natural Earth (https://www.naturalearthdata.com/about/map-update-committee/), thin lines show de jure state borders reported by the Survey of India (https://www.surveyofindia.gov.in/pages/state-maps).

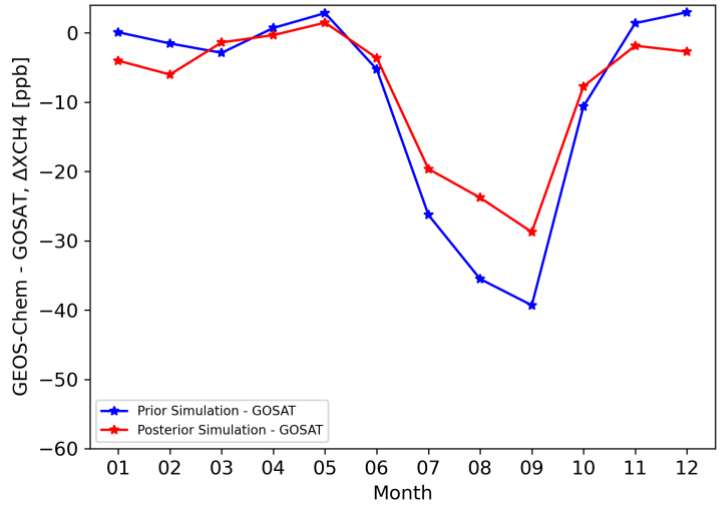

Figure S7. Monthly mean difference between GOSAT and GEOS-Chem prior (blue) and posterior (red) simulations over India.

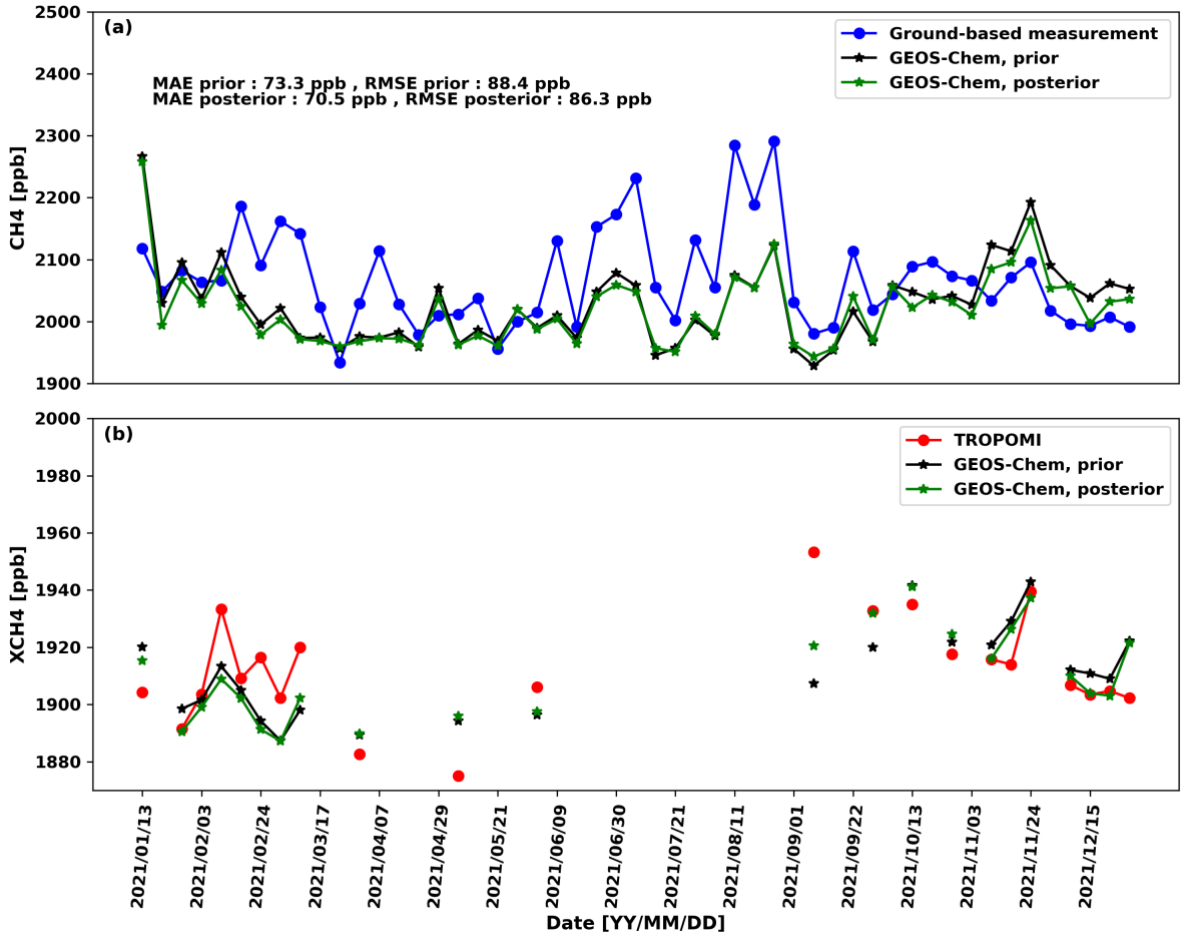

Figure S8. Surface methane concentration measured at Nainital (NTL) (29.36˚N, 79.46˚ E) for 2021 (blue) compared with GEOS-Chem surface - level prior (black) and posterior (green) simulations (a). Total column TROPOMI and modeled XCH4 averaged within a 50 km radius of the Nainital ground-based station (b).

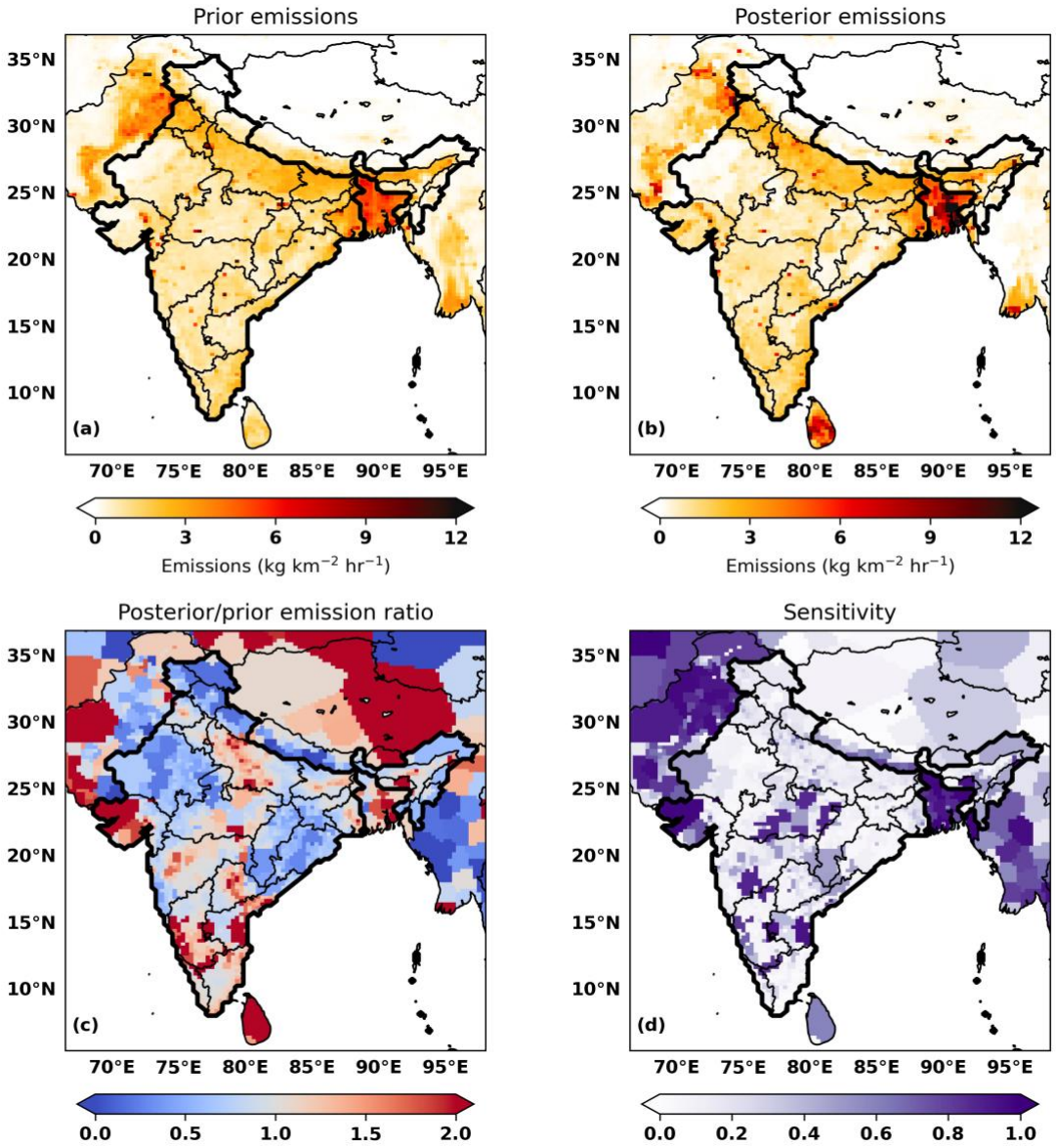

Figure S9. Same as Figure 3 but also shows the results outside of India.

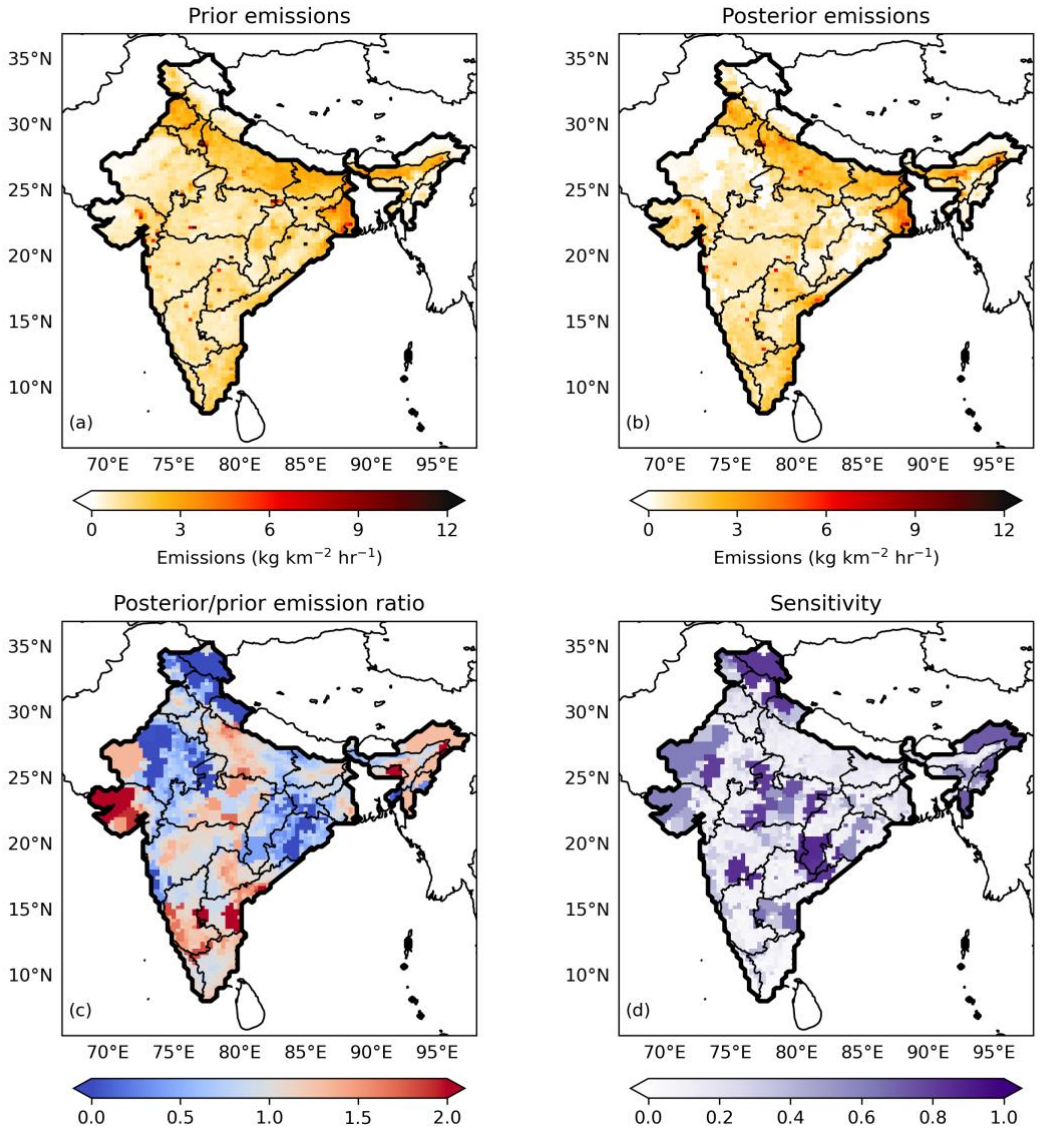

Figure S10. Same as Figure 4 but posterior emission and sensitivity are derived assuming normal errors on the emissions.

Figure S11. Correlation between posterior emission estimates for different sectors derived using the attribution method described in Section 2.8.

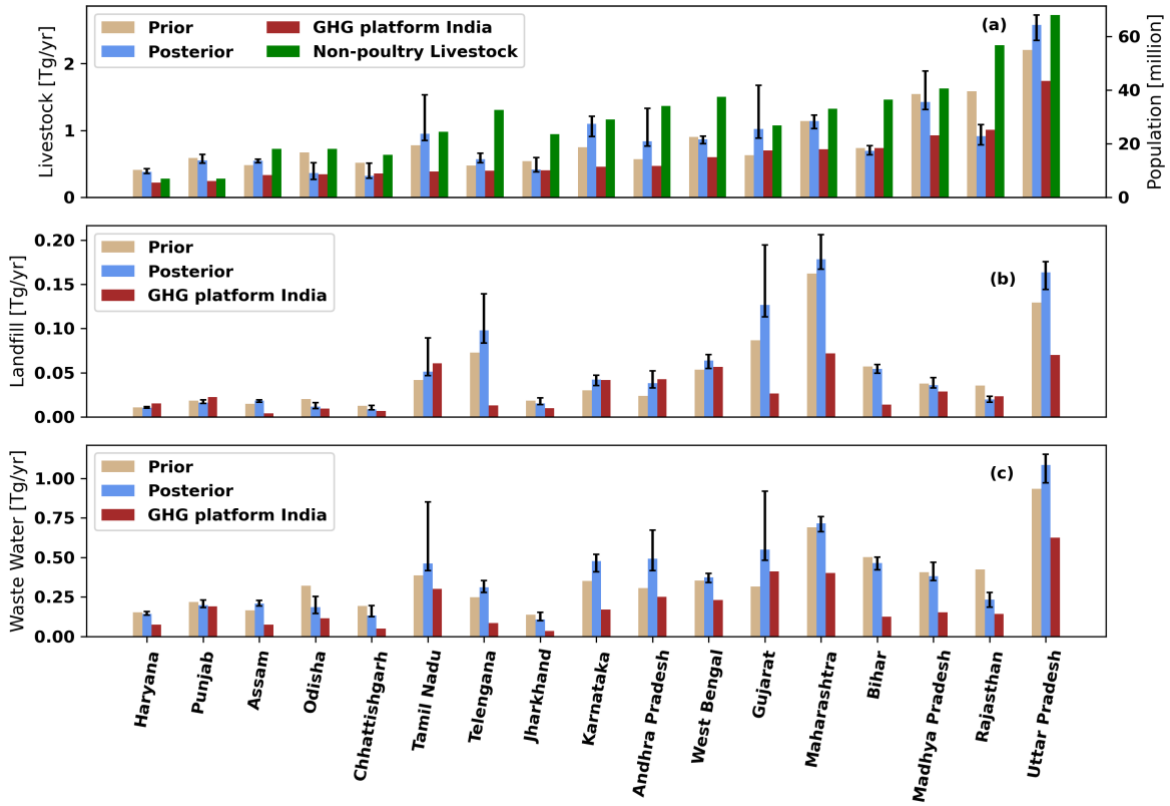

Figure S12. Livestock emissions (a), Landfill (b) and wastewater (c) compared between prior estimates, posterior estimates, and emissions from the GHG platform of India across the 17 states of India that have prior emissions above 0.6 Tg yr^{-1}. The error bars represent the ensemble range derived using the 30 ensemble members. Panel (a) shows the variation in poultry and non-poultry livestock populations across these states derived from 20th livestock census conducted by the Indian government in 2019 (Ministry of Fisheries, Animal Husbandry and Dairying, 2019).

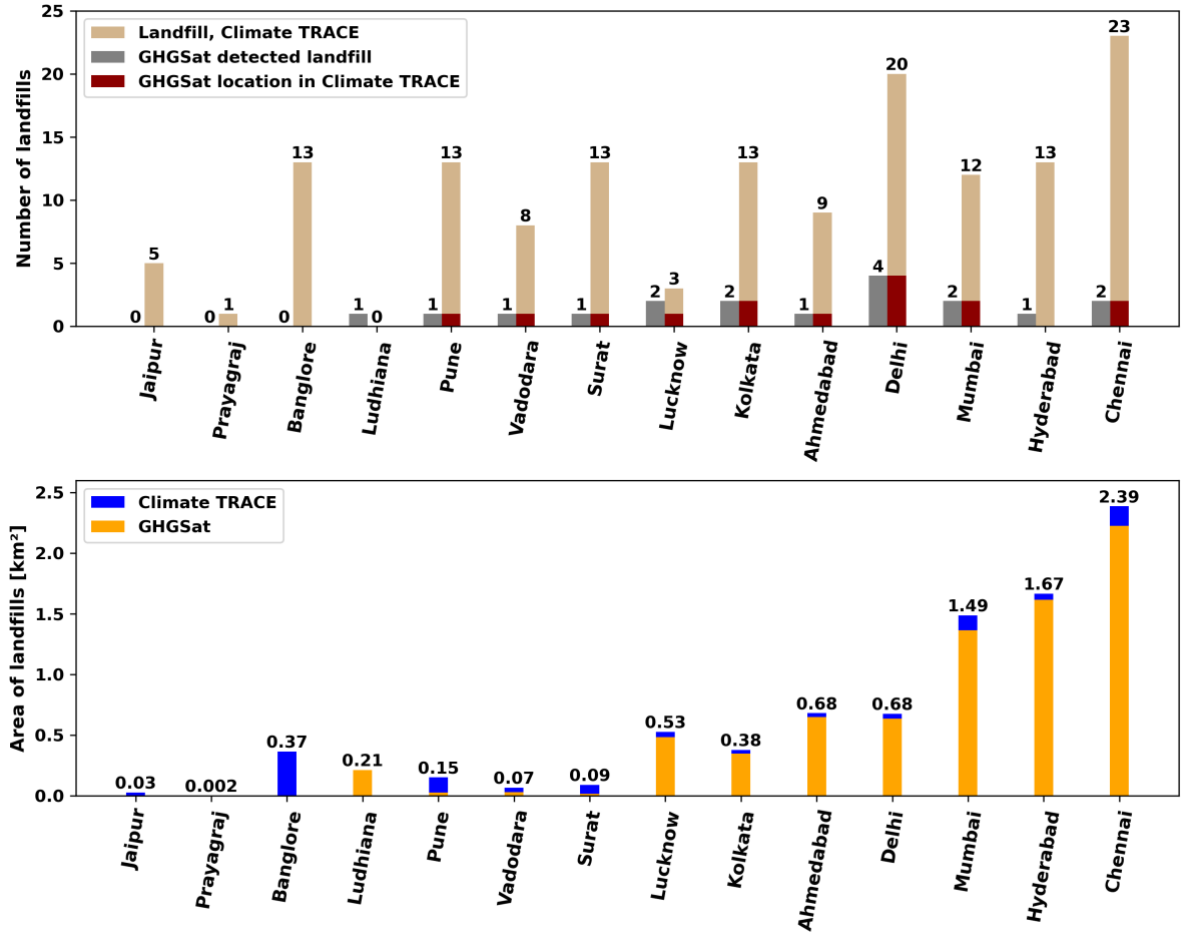

Figure S13. Comparison of the number of solid waste disposal sites(top) and their cumulative area (bottom) as obtained from Climate TRACE and observed by GHGSat within the 14 cities.

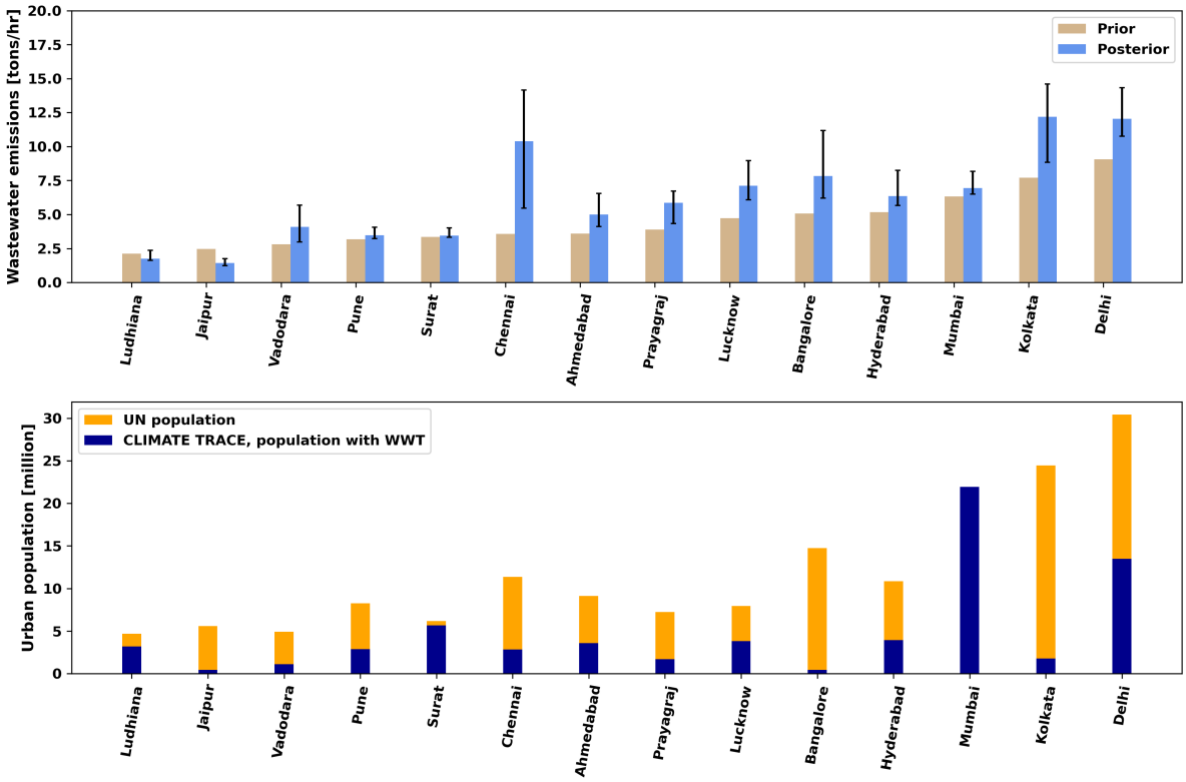

Figure S14. Prior and posterior wastewater emissions across the 14 cities (top). Total prior and posterior wastewater emissions are calculated as the cumulative sum of emissions across nine grids surrounding each city center. Error bars represent the uncertainty in posterior wastewater emissions, derived from the ensemble. The total urban population based on UN population density maps and the population served by wastewater treatment facilities based on Climate TRACE is shown in the bottom panel.