



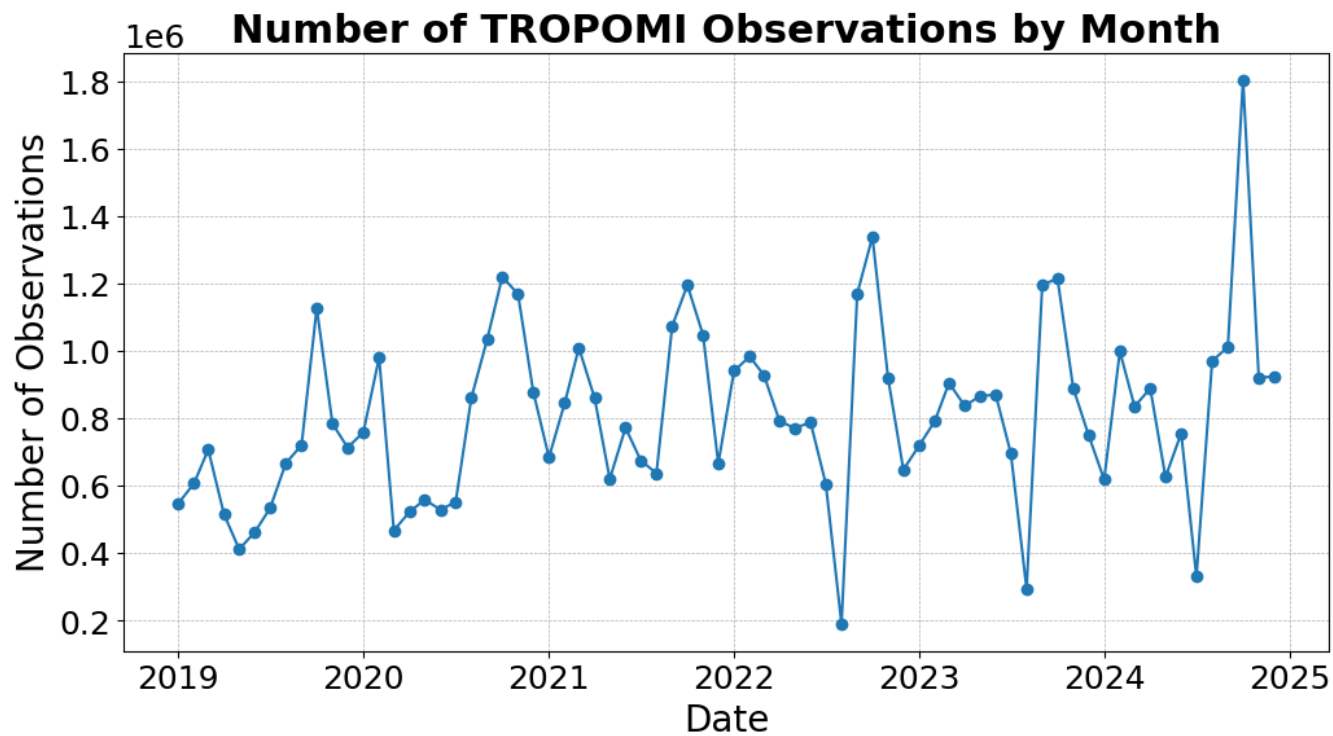
*Supplement of*

## **Quantifying national, state, and oil/gas field methane emissions and trends in the US (2019–2024) through high resolution inversion of satellite observations**

**Lucas A. Estrada et al.**

*Correspondence to:* Lucas A. Estrada (lestrada@g.harvard.edu)

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10 Figure S1: Count of TROPOMI observations over the inversion domain aggregated by month. Annual inversions ingest all observations for the corresponding year.

## Emissions Trend Uncertainties Across Sectors

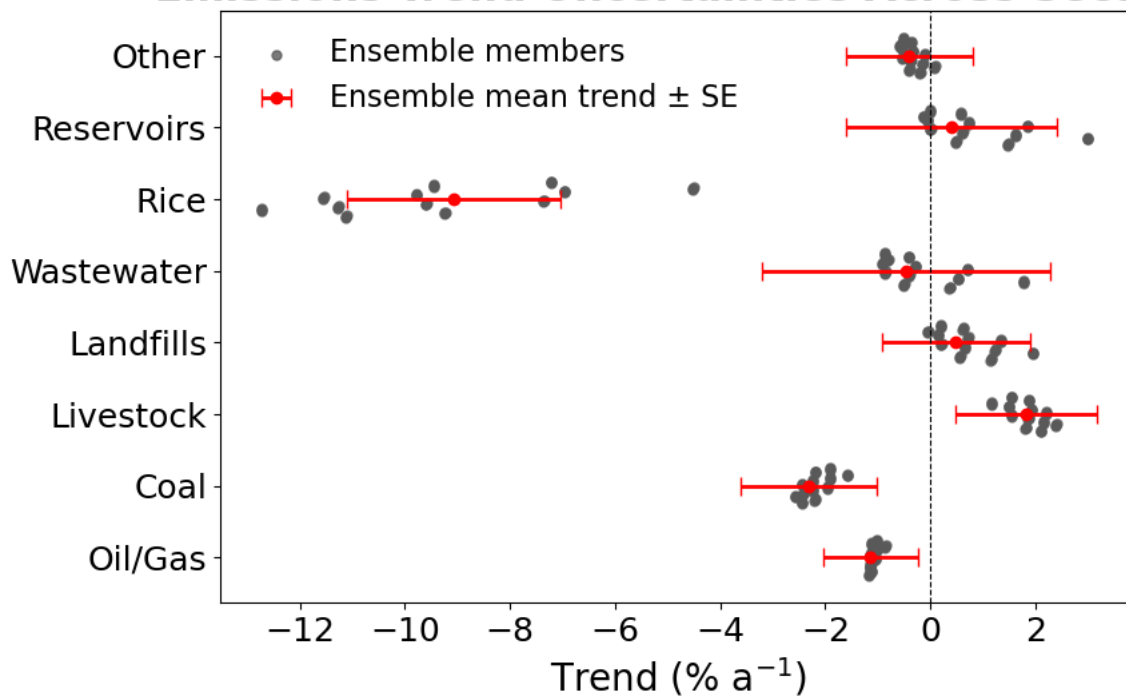


Figure S2: Comparison of trends for individual ensemble members with the ensemble mean trend and standard error. Trends are for 2019-2024. Each grey marker corresponds to the regression trend of a single ensemble member across all years.

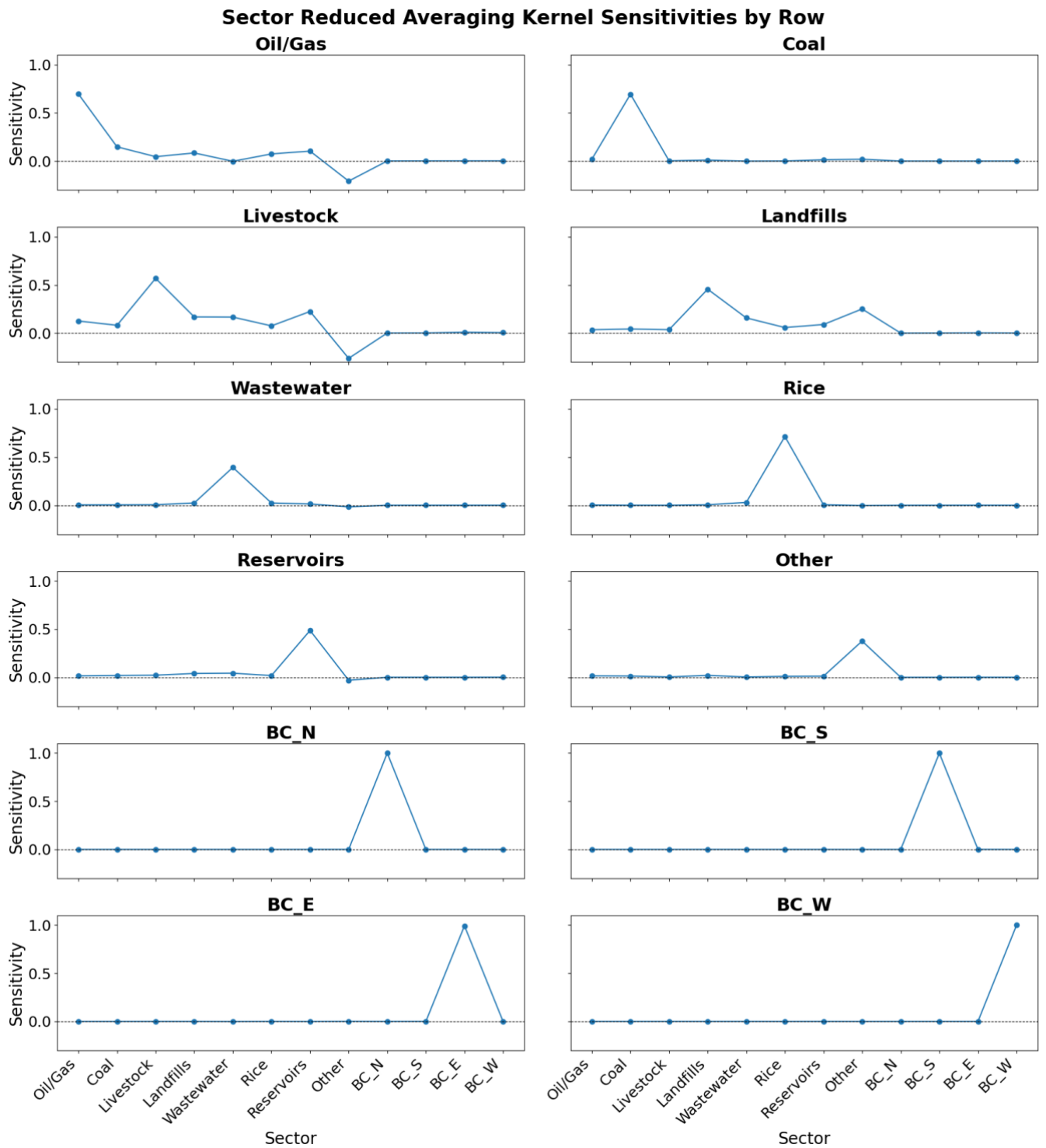


Figure S3: Reduced averaging kernel row by sector for 2024 inversion. Boundary condition (BC) sensitivity rows for each cardinal domain edge are also shown. Averaging kernel sensitivity on the diagonal (i.e., to the same sector) indicates a strong

20 observational constraint on that sector's emissions. Off-diagonal sensitivity (i.e., to different sectors) indicates leakage between sectors caused by the spatial overlap of sector emissions, resulting in misattribution of observational information among sectors (Hancock et al., 2026).

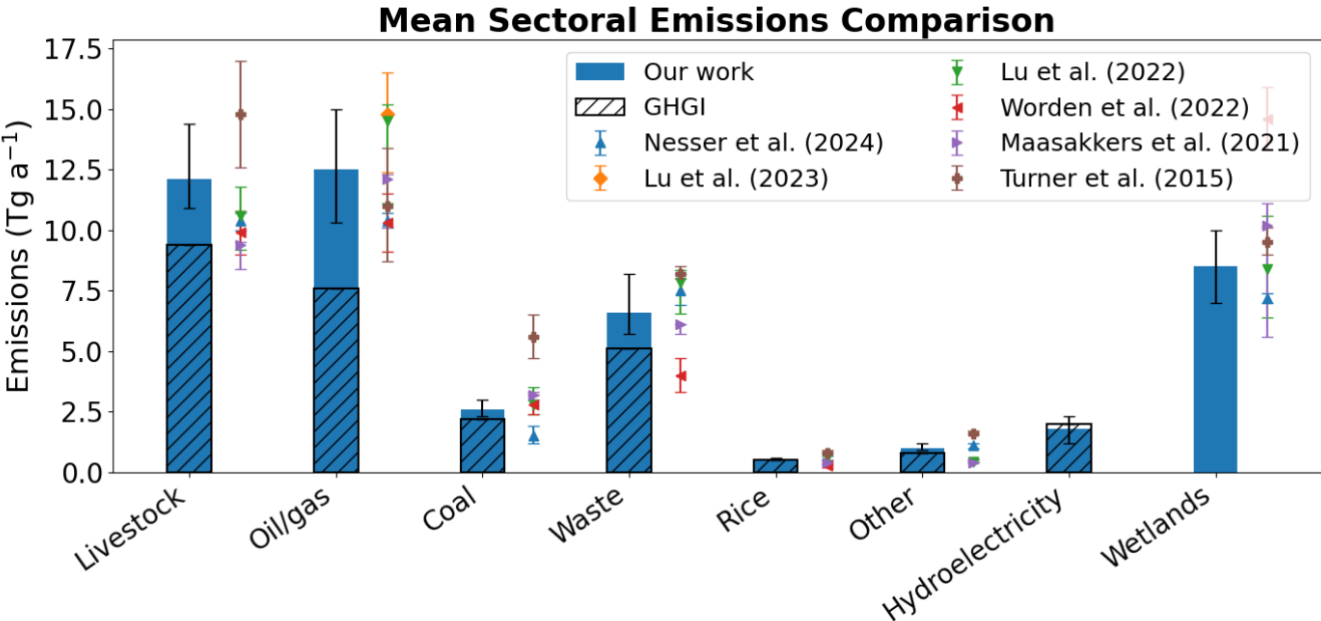


Figure S4: Comparison of national emissions estimate with other studies. This work is the mean for 2019-2024. Error bars for our work represent the range from the ensemble of estimates.

**Table S1: Anthropogenic emissions and trends for 48 states<sup>a</sup>**

| State       | Anthropogenic Mean (Tg a <sup>-1</sup> ) | Annual Trend (% a <sup>-1</sup> ) | Livestock emissions (Tg a <sup>-1</sup> ) | Oil/Gas emissions (Tg a <sup>-1</sup> ) | Coal emissions (Tg a <sup>-1</sup> ) | Landfills emissions (Tg a <sup>-1</sup> ) | Reservoirs emissions (Tg a <sup>-1</sup> ) | Rice emissions (Tg a <sup>-1</sup> ) | Wastewater emissions (Tg a <sup>-1</sup> ) | Other Anthropogenic emissions (Tg a <sup>-1</sup> ) | Sensitivity <sup>b</sup> |
|-------------|------------------------------------------|-----------------------------------|-------------------------------------------|-----------------------------------------|--------------------------------------|-------------------------------------------|--------------------------------------------|--------------------------------------|--------------------------------------------|-----------------------------------------------------|--------------------------|
| Alabama     | 0.9[0.7, 1.0]                            | 3.0 ± 2.4                         | [0.1, 0.14]                               | [0.11, 0.16]                            | [0.16, 0.23]                         | [0.17, 0.25]                              | [0.14, 0.19]                               | [0.0, 0.0]                           | [0.03, 0.05]                               | [0.01, 0.01]                                        | 0.49                     |
| Arizona     | 0.1[0.0, 0.2]                            | 11.8 ± 8.0                        | [0.0, 0.09]                               | [0.01, 0.04]                            | [0.0, 0.0]                           | [0.01, 0.05]                              | [-0.01, 0.01]                              | [0.0, 0.0]                           | [0.0, 0.01]                                | [0.0, 0.0]                                          | 0.35                     |
| Arkansas    | 0.7[0.6, 0.9]                            | -5.3 ± 1.1                        | [0.14, 0.19]                              | [0.15, 0.21]                            | [0.01, 0.02]                         | [0.06, 0.1]                               | [0.06, 0.09]                               | [0.17, 0.26]                         | [0.01, 0.02]                               | [0.01, 0.01]                                        | 0.57                     |
| California  | 1.5[1.1, 1.9]                            | 1.6 ± 2.4                         | [0.75, 1.08]                              | [0.12, 0.23]                            | [0.0, 0.0]                           | [0.16, 0.35]                              | [0.0, 0.05]                                | [0.05, 0.1]                          | [0.02, 0.05]                               | [0.01, 0.03]                                        | 0.72                     |
| Colorado    | 0.7[0.5, 0.8]                            | 2.3 ± 5.1                         | [0.16, 0.28]                              | [0.28, 0.39]                            | [0.01, 0.04]                         | [0.04, 0.08]                              | [0.0, 0.01]                                | [0.0, 0.0]                           | [0.01, 0.01]                               | [0.01, 0.01]                                        | 0.67                     |
| Connecticut | 0.0[0.0, 0.0]                            | 1.1 ± 3.2                         | [0.0, 0.0]                                | [0.01, 0.01]                            | [0.0, 0.0]                           | [0.01, 0.01]                              | [0.0, 0.0]                                 | [0.0, 0.0]                           | [0.0, 0.0]                                 | [0.0, 0.0]                                          | 0.19                     |
| Delaware    | 0.0[0.0, 0.0]                            | -3.2 ± 7.6                        | [0.0, 0.0]                                | [0.0, 0.0]                              | [0.0, 0.0]                           | [0.01, 0.01]                              | [0.0, 0.0]                                 | [0.0, 0.0]                           | [0.0, 0.01]                                | [0.0, 0.0]                                          | 0.24                     |
| Florida     | 0.7[0.5, 0.9]                            | 8.3 ± 3.6                         | [0.15, 0.29]                              | [0.04, 0.07]                            | [0.0, 0.0]                           | [0.27, 0.5]                               | [0.0, 0.0]                                 | [0.0, 0.0]                           | [0.02, 0.02]                               | [0.02, 0.03]                                        | 0.39                     |
| Georgia     | 0.8[0.6, 0.9]                            | -0.4 ± 4.6                        | [0.14, 0.2]                               | [0.05, 0.08]                            | [0.0, 0.0]                           | [0.27, 0.48]                              | [0.09, 0.14]                               | [0.0, 0.0]                           | [0.02, 0.03]                               | [0.02, 0.02]                                        | 0.44                     |
| Idaho       | 0.2[0.1, 0.3]                            | 1.3 ± 11.2                        | [0.09, 0.25]                              | [-0.0, 0.01]                            | [0.0, 0.0]                           | [0.01, 0.02]                              | [-0.02, 0.07]                              | [0.0, 0.0]                           | [0.0, 0.0]                                 | [0.0, 0.0]                                          | 0.5                      |
| Illinois    | 1.0[0.8, 1.3]                            | -0.1 ± 5.9                        | [0.2, 0.34]                               | [0.11, 0.2]                             | [0.15, 0.21]                         | [0.22, 0.41]                              | [0.01, 0.02]                               | [0.0, 0.0]                           | [0.04, 0.06]                               | [0.03, 0.05]                                        | 0.46                     |

|                |                |             |              |               |              |               |               |              |              |              |      |
|----------------|----------------|-------------|--------------|---------------|--------------|---------------|---------------|--------------|--------------|--------------|------|
| Indiana        | 0.8[0.6, 1.0]  | 0.2 ± 4.0   | [0.18, 0.28] | [0.07, 0.11]  | [0.15, 0.23] | [0.16, 0.3]   | [0.0, 0.0]    | [0.0, 0.0]   | [0.02, 0.04] | [0.03, 0.04] | 0.44 |
| Iowa           | 0.9[0.8, 1.2]  | 9.1 ± 5.1   | [0.62, 0.91] | [0.05, 0.08]  | [0.0, 0.0]   | [0.08, 0.16]  | [0.0, 0.0]    | [0.0, 0.0]   | [0.01, 0.02] | [0.01, 0.01] | 0.49 |
| Kansas         | 1.3[1.1, 1.5]  | 6.6 ± 2.2   | [0.6, 0.79]  | [0.45, 0.58]  | [0.0, 0.0]   | [0.06, 0.08]  | [0.0, 0.0]    | [0.0, 0.0]   | [0.01, 0.01] | [0.03, 0.03] | 0.55 |
| Kentucky       | 0.8[0.7, 1.0]  | -1.0 ± 2.8  | [0.19, 0.26] | [0.13, 0.2]   | [0.13, 0.21] | [0.15, 0.21]  | [0.02, 0.1]   | [0.0, 0.0]   | [0.01, 0.01] | [0.03, 0.04] | 0.5  |
| Louisiana      | 1.2[1.0, 1.5]  | -11.0 ± 2.3 | [0.06, 0.08] | [0.51, 0.79]  | [0.0, 0.0]   | [0.18, 0.3]   | [0.01, 0.04]  | [0.09, 0.12] | [0.08, 0.11] | [0.03, 0.05] | 0.58 |
| Maine          | 0.1[-0.0, 0.1] | 11.7 ± 15.9 | [0.0, 0.01]  | [0.0, 0.01]   | [0.0, 0.0]   | [-0.0, 0.02]  | [-0.0, 0.09]  | [0.0, 0.0]   | [-0.0, 0.0]  | [-0.0, 0.01] | 0.44 |
| Maryland       | 0.1[0.1, 0.1]  | -3.6 ± 10.5 | [0.01, 0.02] | [0.01, 0.03]  | [0.0, 0.0]   | [0.02, 0.05]  | [0.0, 0.0]    | [0.0, 0.0]   | [0.0, 0.01]  | [0.0, 0.01]  | 0.26 |
| Massachusetts  | 0.1[0.0, 0.1]  | -4.0 ± 2.6  | [0.0, 0.0]   | [0.01, 0.02]  | [0.0, 0.0]   | [0.02, 0.02]  | [0.0, 0.0]    | [0.0, 0.0]   | [0.0, 0.0]   | [0.0, 0.01]  | 0.21 |
| Michigan       | 0.8[0.7, 1.0]  | 3.2 ± 4.8   | [0.23, 0.33] | [0.13, 0.2]   | [0.0, 0.0]   | [0.23, 0.35]  | [0.01, 0.01]  | [0.0, 0.0]   | [0.03, 0.05] | [0.03, 0.05] | 0.58 |
| Minnesota      | 0.6[0.5, 0.8]  | 0.5 ± 4.2   | [0.39, 0.6]  | [0.03, 0.05]  | [0.0, 0.0]   | [0.05, 0.08]  | [0.0, 0.01]   | [0.0, 0.0]   | [0.01, 0.01] | [0.01, 0.02] | 0.56 |
| Mississippi    | 0.3[0.3, 0.5]  | -4.3 ± 3.5  | [0.09, 0.13] | [0.1, 0.14]   | [0.0, 0.0]   | [0.06, 0.11]  | [0.0, 0.0]    | [0.02, 0.04] | [0.01, 0.02] | [0.01, 0.01] | 0.44 |
| Missouri       | 1.0[0.8, 1.2]  | 3.7 ± 4.2   | [0.42, 0.62] | [0.04, 0.07]  | [0.0, 0.0]   | [0.08, 0.14]  | [0.08, 0.11]  | [0.04, 0.05] | [0.11, 0.16] | [0.02, 0.02] | 0.49 |
| Montana        | 0.3[0.1, 0.4]  | 1.9 ± 3.8   | [0.1, 0.22]  | [0.04, 0.06]  | [0.0, 0.02]  | [0.0, 0.01]   | [-0.01, 0.09] | [0.0, 0.0]   | [0.0, 0.0]   | [0.0, 0.01]  | 0.4  |
| Nebraska       | 0.9[0.8, 1.2]  | 1.7 ± 4.1   | [0.66, 0.97] | [0.04, 0.07]  | [0.0, 0.0]   | [0.06, 0.09]  | [0.0, 0.01]   | [0.0, 0.0]   | [0.01, 0.01] | [0.01, 0.01] | 0.52 |
| Nevada         | 0.0[-0.1, 0.1] | 2.9 ± 7.8   | [-0.0, 0.04] | [-0.01, 0.01] | [0.0, 0.0]   | [-0.02, 0.01] | [-0.03, 0.04] | [0.0, 0.0]   | [-0.0, 0.0]  | [-0.0, 0.0]  | 0.17 |
| New Hampshire  | 0.0[0.0, 0.1]  | -5.2 ± 11.0 | [0.0, 0.01]  | [0.0, 0.0]    | [0.0, 0.0]   | [-0.0, 0.02]  | [0.01, 0.02]  | [0.0, 0.0]   | [0.0, 0.0]   | [0.0, 0.01]  | 0.31 |
| New Jersey     | 0.1[0.0, 0.1]  | 3.2 ± 3.9   | [0.0, 0.0]   | [0.02, 0.02]  | [0.0, 0.0]   | [0.02, 0.04]  | [0.0, 0.0]    | [0.0, 0.0]   | [0.0, 0.01]  | [0.0, 0.0]   | 0.3  |
| New Mexico     | 1.3[1.0, 1.5]  | 0.8 ± 4.2   | [0.12, 0.24] | [0.86, 1.09]  | [0.01, 0.03] | [0.03, 0.05]  | [0.01, 0.03]  | [0.0, 0.0]   | [0.0, 0.0]   | [0.01, 0.01] | 0.57 |
| New York       | 0.6[0.5, 0.7]  | 4.8 ± 3.6   | [0.21, 0.29] | [0.14, 0.19]  | [0.0, 0.0]   | [0.1, 0.13]   | [0.02, 0.03]  | [0.0, 0.0]   | [0.02, 0.03] | [0.04, 0.05] | 0.51 |
| North Carolina | 0.5[0.4, 0.6]  | 0.5 ± 2.9   | [0.19, 0.26] | [0.03, 0.04]  | [0.0, 0.0]   | [0.15, 0.23]  | [0.03, 0.04]  | [0.0, 0.0]   | [0.02, 0.02] | [0.01, 0.01] | 0.51 |
| North Dakota   | 0.4[0.2, 0.5]  | 4.3 ± 5.8   | [0.16, 0.24] | [0.08, 0.15]  | [0.0, 0.0]   | [0.02, 0.05]  | [-0.03, 0.05] | [0.0, 0.0]   | [0.0, 0.0]   | [0.0, 0.01]  | 0.48 |
| Ohio           | 1.4[1.1, 1.6]  | -1.8 ± 4.3  | [0.22, 0.38] | [0.34, 0.45]  | [0.19, 0.25] | [0.28, 0.43]  | [0.0, 0.0]    | [0.0, 0.0]   | [0.03, 0.04] | [0.07, 0.1]  | 0.58 |
| Oklahoma       | 2.2[1.8, 2.7]  | -1.4 ± 1.0  | [0.53, 0.67] | [0.93, 1.46]  | [0.01, 0.03] | [0.14, 0.21]  | [0.14, 0.22]  | [0.0, 0.0]   | [0.01, 0.02] | [0.04, 0.06] | 0.62 |
| Oregon         | 0.1[0.0, 0.2]  | -1.0 ± 9.3  | [0.01, 0.1]  | [-0.0, 0.01]  | [0.0, 0.0]   | [-0.0, 0.03]  | [-0.01, 0.02] | [0.0, 0.0]   | [-0.0, 0.0]  | [-0.0, 0.01] | 0.38 |
| Pennsylvania   | 1.6[1.3, 2.0]  | 1.0 ± 2.3   | [0.24, 0.41] | [0.54, 0.89]  | [0.3, 0.38]  | [0.15, 0.23]  | [0.0, 0.0]    | [0.0, 0.0]   | [0.02, 0.03] | [0.08, 0.11] | 0.58 |
| Rhode Island   | 0.0[0.0, 0.0]  | -2.2 ± 3.8  | [0.0, 0.0]   | [0.0, 0.0]    | [0.0, 0.0]   | [0.0, 0.0]    | [0.0, 0.0]    | [0.0, 0.0]   | [0.0, 0.0]   | [0.0, 0.0]   | 0.07 |
| South Carolina | 0.3[0.2, 0.4]  | -3.0 ± 7.2  | [0.04, 0.07] | [0.02, 0.04]  | [0.0, 0.0]   | [0.07, 0.14]  | [0.04, 0.11]  | [0.0, 0.0]   | [0.01, 0.01] | [0.01, 0.01] | 0.5  |
| South Dakota   | 0.7[0.5, 0.8]  | 1.1 ± 6.2   | [0.42, 0.64] | [0.01, 0.01]  | [0.0, 0.0]   | [0.02, 0.03]  | [0.05, 0.15]  | [0.0, 0.0]   | [0.0, 0.01]  | [0.0, 0.01]  | 0.47 |
| Tennessee      | 0.8[0.6, 1.0]  | -3.4 ± 3.8  | [0.17, 0.3]  | [0.08, 0.12]  | [0.0, 0.0]   | [0.16, 0.25]  | [0.2, 0.27]   | [0.01, 0.02] | [0.02, 0.03] | [0.02, 0.03] | 0.49 |
| Texas          | 7.2[5.8, 8.6]  | -2.6 ± 1.3  | [1.34, 1.78] | [3.38, 5.32]  | [0.01, 0.02] | [0.61, 0.85]  | [0.15, 0.2]   | [0.04, 0.07] | [0.07, 0.12] | [0.18, 0.23] | 0.69 |
| Utah           | 0.4[0.2, 0.5]  | -4.8 ± 8.1  | [0.05, 0.1]  | [0.15, 0.27]  | [0.03, 0.04] | [0.01, 0.03]  | [-0.02, 0.03] | [0.0, 0.0]   | [0.0, 0.0]   | [0.0, 0.01]  | 0.38 |
| Vermont        | 0.0[0.0, 0.1]  | 2.4 ± 8.9   | [0.02, 0.04] | [0.0, 0.0]    | [0.0, 0.0]   | [0.0, 0.01]   | [0.0, 0.01]   | [0.0, 0.0]   | [0.0, 0.0]   | [0.0, 0.0]   | 0.41 |
| Virginia       | 0.5[0.4, 0.6]  | 4.3 ± 4.9   | [0.11, 0.18] | [0.04, 0.06]  | [0.08, 0.12] | [0.1, 0.16]   | [0.03, 0.05]  | [0.0, 0.0]   | [0.01, 0.02] | [0.01, 0.01] | 0.45 |
| Washington     | 0.1[0.0, 0.3]  | -0.3 ± 9.1  | [0.02, 0.02] | [0.0, 0.02]   | [0.0, 0.0]   | [-0.01, 0.01] | [0.01, 0.03]  | [0.0, 0.0]   | [0.0, 0.01]  | [-0.0, 0.01] | 0.51 |

|               |               |            |              |              |              |              |              |            |              |              |      |
|---------------|---------------|------------|--------------|--------------|--------------|--------------|--------------|------------|--------------|--------------|------|
|               |               |            | 0.12]        |              |              | 0.06]        |              |            |              |              |      |
| West Virginia | 1.8[1.5, 2.1] | -0.7 ± 2.9 | [0.07, 0.1]  | [0.48, 0.79] | [0.88, 1.08] | [0.05, 0.07] | [0.0, 0.0]   | [0.0, 0.0] | [0.0, 0.01]  | [0.02, 0.04] | 0.65 |
| Wisconsin     | 0.7[0.6, 0.8] | 1.0 ± 5.1  | [0.42, 0.57] | [0.03, 0.04] | [0.0, 0.0]   | [0.09, 0.14] | [0.02, 0.04] | [0.0, 0.0] | [0.01, 0.01] | [0.02, 0.02] | 0.55 |
| Wyoming       | 0.5[0.4, 0.7] | -2.9 ± 5.9 | [0.07, 0.11] | [0.21, 0.34] | [0.03, 0.14] | [0.0, 0.01]  | [0.04, 0.06] | [0.0, 0.0] | [-0.0, 0.0]  | [0.0, 0.0]   | 0.57 |

<sup>a</sup> Numbers in brackets represent the range from the ensemble.

<sup>b</sup> Averaging kernel sensitivities from the reduced averaging kernel matrix (Nesser et al., 2024) for the 2019-2024 mean of ensemble members using normal error pdfs. They describe the relative contributions of the TROPOMI observations and the prior estimates to the posterior estimates. Value of 1 indicates 100% contribution from the observations; value of 0 indicates no contribution from the observations.

### California Inventory Emissions and Trends Comparison

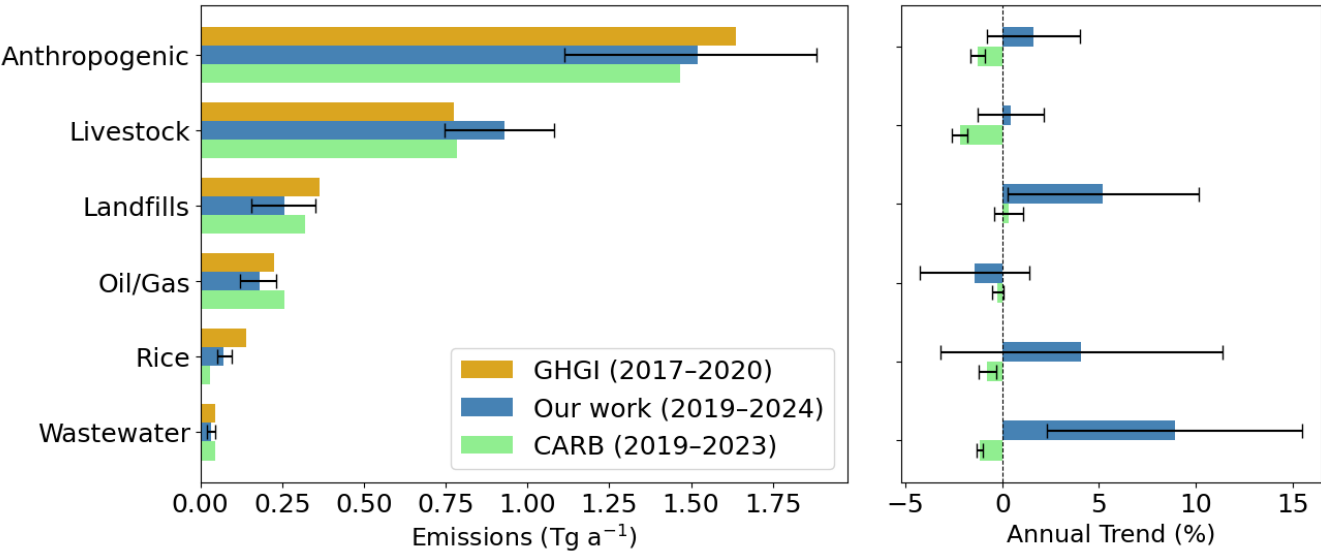


Figure S5: Comparison of trends and estimates of inventory values for major sectors in California. Upper panel shows the mean emissions for each inventory (period in legend). Error bars on mean are the range from the inversion ensemble. Lower panel shows the trend of the state inventory and our work calculated with OLS regression. Error bars are the standard error from the regression line.

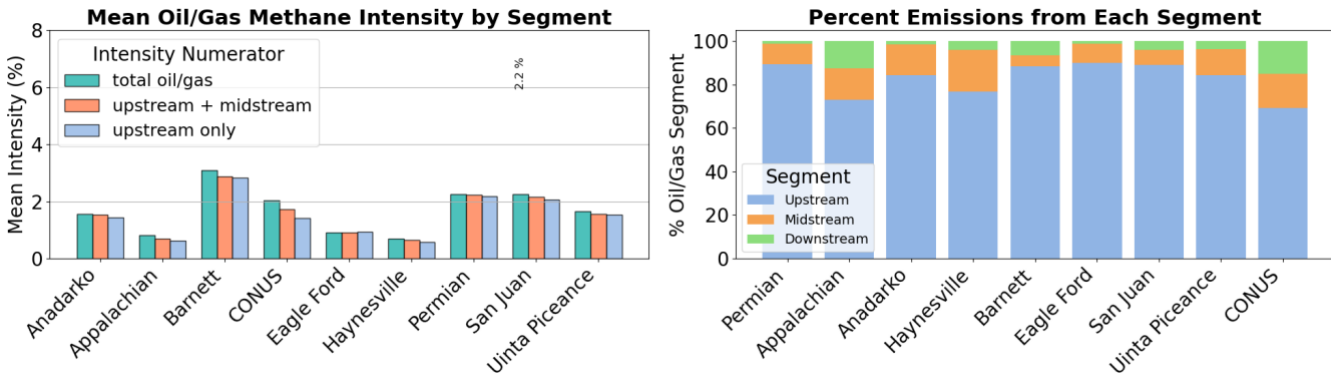


Figure S6: Mean oil/gas production methane intensities with different segment definitions and breakdown of segment contributions to emissions. Left panel calculates methane intensity including: all oil/gas emissions, upstream and midstream emissions, and only upstream emissions. Percent of emissions from each segment (upstream, midstream, downstream) for individual production fields and CONUS. Segment emissions calculated using GHGI emission distributions for each grid cell applied to posterior emissions.