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Missing wintertime methane emissions from New York City related to combustion

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Supplement

Supplemental Tables

Table S1. Annual methane emissions from various inventories by sector and totals for the New York City (NYC) subregion of the NYCMA study domain (see Table 1). The NYC area is 2.81×10^3 km^2 (6.0% of NYCMA).

Methane Inventory Emissions [Gg CH_4 yr^{-1}] (Percentage of Total [%])	EDGAR v6.0 2018	EDGAR v8.0 2018	EPA GHGI v2016 2012	EPA GHGI v2023 2018	EPA GHGI v2023 EE 2018	Pitt High-Res. Inventory 2019
Landfill	14.1 (18.9)	10.6 (24.9)	24.8 (33.5)	12.1 (22.5)	12.1 (17.0)	9.9 (10.1)
Natural Gas Distribution	4.4 (5.9)	4.4 (10.3)	19.0 (25.7)	19.1 (35.7)	23.2 (32.7)	31.2 (31.7)
Natural Gas Transmission			4.7 (6.3)	2.4 (4.5)	2.7 (3.7)	1.1 (1.1)
Natural Gas Post-meter					11.9 (16.7)	27.2 (27.7)
Wastewater	41.2 (55.4)	11.4 (26.7)	16.3 (21.9)	10.9 (20.4)	13.0 (18.4)	20.7 (21.1)
Stationary Combustion	4.6 (6.2)	11.9 (27.9)	6.8 (9.2)	5.9 (10.9)	5.8 (8.2)	5.6 (5.7)
Other	10.2 (13.6)	4.35 (10.2)	2.6 (3.4)	3.2 (5.9)	2.3 (3.2)	2.5 (2.6)
Total	74.5	42.7	74.1	53.6	70.9	98.4
Total [kg s^{-1}]	*2.36*	*1.35*	*2.35*	*1.70*	*2.25*	*3.12*

Table S2. Observation-informed methane (CH_4) and CO emission rates (and 95% confidence intervals) from the NYCMA for various time periods prior to and during the COVID-19 shutdown in 2020. Area of the NYCMA is 46.7×10^3 km^2.

	[kg s^{-1}]	15 Jan–29 Feb	1–14 Mar	15–31 Mar	1–14 Apr	15 Apr–15 May
CH_4	11–16 h	19.4 (16.6–22.8)	16.2 (12.3–20.2)	12.6 (9.3–16.1)	12.0 (8.0–15.8)	10.1 (8.1–12.7)
	24-hr	11.4 (10.5–12.3)	10.2 (8.9–11.7)	7.3 (6.5–8.3)	11.0 (9.7–12.3)	9.1 (8.5–9.8)
CO	11–16 h	44.6 (39.6–49.7)	44.9 (36.4–54.4)	22.9 (19.5–26.1)	22.0 (17.2–26.2)	22.0 (18.8–25.7)
	24-hr	24.2 (22.9–25.6)	19.9 (17.6–22.5)	14.5 (13.0–16.0)	15.6 (14.0–17.3)	14.1 (13.0–15.2)

Table S3. Monthly afternoon (11–16 h EST) observation-informed methane emission rates (and 95% confidence intervals) from the NYCMA over the study period.

[kg s^{-1}]	January	February	March	April	May
2019		27.4 (18.9–35.7)	15.7 (13.0–18.6)	17.9 (13.6–23.1)	
2020	18.7 (15.3–22.6)	20.4 (16.0–25.6)	14.0 (11.5–16.6)	10.2 (7.9–12.7)	6.8 (5.0–8.8)
2021	30.4 (23.6–37.5)	13.1 (8.6–18.9)	10.8 (7.1–15.3)	14.1 (9.0–21.4)	
2022	12.1 (8.7–15.5)	12.4 (8.1–17.8)	15.0 (10.8–19.7)		10.1 (6.8–13.5)
2023	17.0 (12.9–23.5)		19.2 (14.5–23.4)	11.4 (7.4–15.9)	10.2 (6.9–13.9)
2024	14.3 (12.1–16.7)	12.8 (10.1–15.8)	15.2 (13.0–17.7)	14.3 (11.6–17.3)	10.2 (8.3–12.3)

Table S4. Monthly afternoon (11–16 h EST) observation-informed CO emission rates (and 95% confidence intervals) from the NYCMA over the study period.

[kg s^{-1}]	January	February	March	April	May
2019		56.9 (50.1–64.9)	39.4 (34.7–44.7)	48.0 (39.3–60.1)	
2020	41.2 (36.1–46.3)	49.1 (40.1–59.4)	31.4 (27.2–36.0)	21.8 (18.7–24.9)	13.5 (10.8–16.6)
2021	52.5 (39.2–65.3)	33.5 (23.8–43.1)	32.0 (21.4–44.2)	44.8 (33.2–59.0)	
2022	36.7 (27.4–45.3)	41.4 (31.3–50.7)	41.0 (33.7–47.4)		29.1 (24.4–33.7)
2023	29.5 (18.4–39.1)		53.7 (40.3–66.9)	39.5 (28.7–51.5)	39.5 (27.5–53.8)
2024	34.3 (30.1–38.9)	38.9 (29.6–49.3)	43.3 (33.7–54.0)	46.4 (36.2–56.6)	26.3 (23.2–29.4)

Table S5. Monthly 24-hour (0–0 h EST) observation-informed methane emission rates (and 95% confidence intervals) from the NYCMA over the study period.

[kg s^{-1}]	January	February	March	April	May
2019		16.2 (14.0–18.8)	10.4 (9.5–11.3)	12.9 (11.1–14.7)	
2020	12.1 (11.0–13.3)	10.6 (9.7–11.7)	8.8 (8.0–9.6)	9.6 (8.8–10.5)	8.6 (7.8–9.3)
2021	12.9 (11.3–14.7)	11.9 (9.8–14.4)	13.3 (10.8–15.7)	12.1 (10.5–14.3)	
2022	9.1 (7.8–10.4)	10.7 (9.4–12.0)	10.4 (8.2–12.7)		8.7 (7.7–9.8)
2023	10.8 (9.5–12.2)		11.6 (10.1–13.1)	8.5 (7.0–10.2)	6.6 (5.4–7.9)
2024	12.6 (11.8–13.5)	9.9 (8.8–11.1)	10.9 (10.1–11.6)	11.4 (10.2–12.8)	7.5 (6.9–8.2)

Table S6. Monthly 24-hour (0–0 h EST) observation-informed CO emission rates (and 95% confidence intervals) from the NYCMA over the study period.

[kg s^{-1}]	January	February	March	April	May
2019		30.4 (27.7–33.3)	21.9 (20.3–23.4)	22.8 (20.5–25.3)	
2020	24.2 (22.5–26.0)	24.1 (22.4–26.1)	17.3 (15.7–18.8)	15.2 (14.1–16.2)	9.6 (8.6–10.7)
2021	23.1 (18.6–28.3)	23.8 (19.3–28.5)	27.4 (22.2–32.5)	25.1 (21.9–29.3)	
2022	21.8 (18.1–25.7)	30.8 (26.5–34.9)	21.9 (17.3–26.4)		18.0 (16.4–19.7)
2023	18.8 (13.3–24.5)		24.3 (19.7–29.0)	21.0 (16.9–25.4)	17.1 (12.3–22.3)
2024	25.6 (24.0–27.3)	24.4 (20.1–28.9)	27.7 (23.1–32.6)	23.9 (20.2–28.0)	12.5 (11.4–13.6)

Supplemental Figures

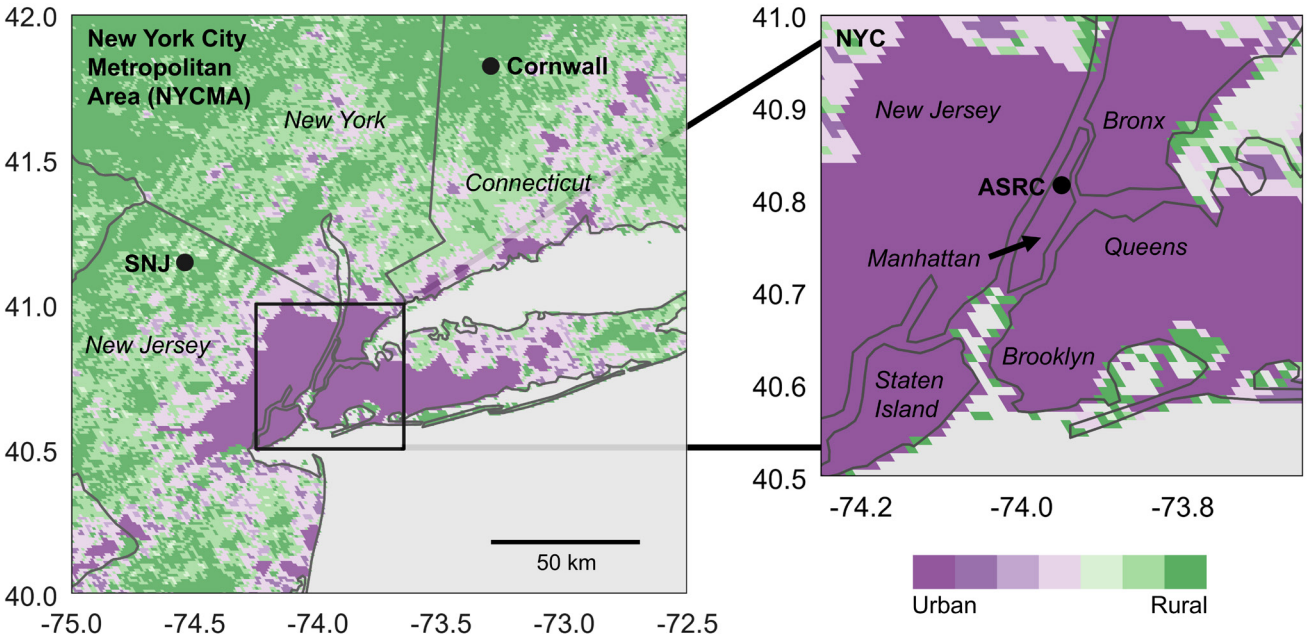
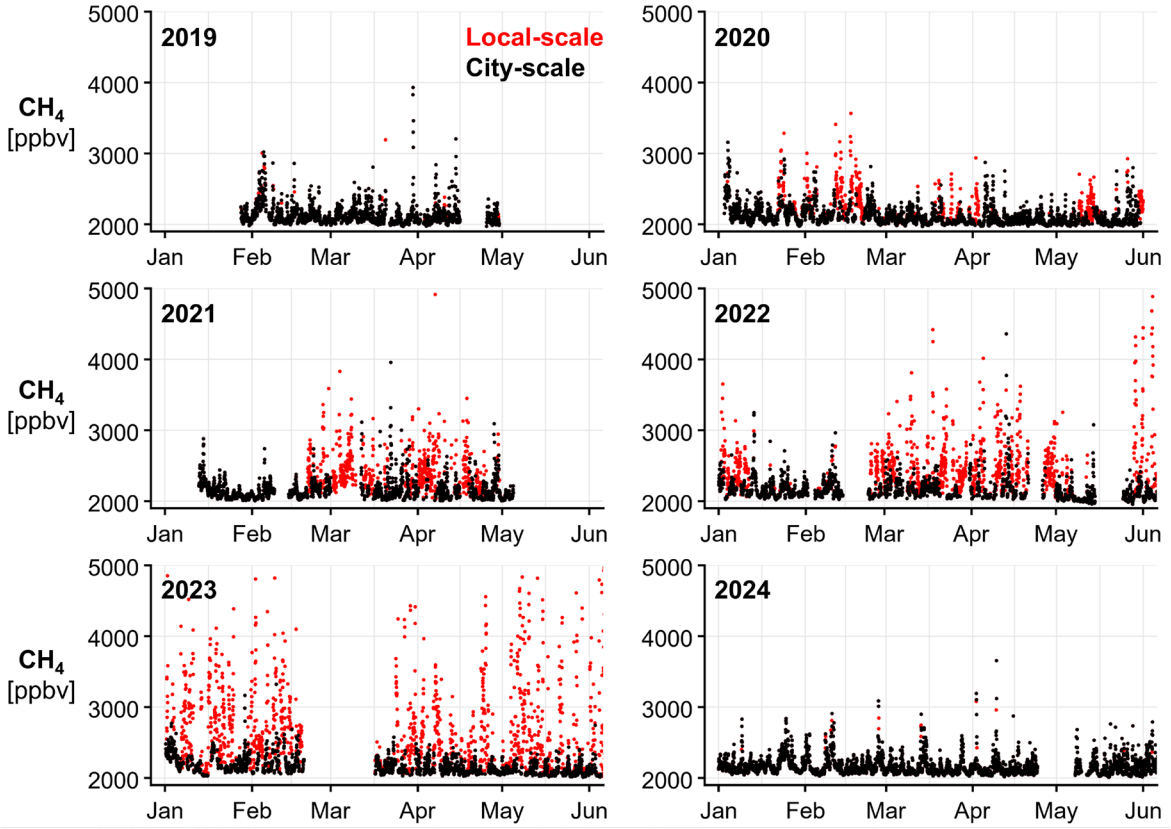


Figure S1. Maps of the New York City Metropolitan Area (NYCMA) study domain (left) and New York City (NYC) subdomain (right) and the locations of the urban core Advanced Science Research Center (ASRC), remote Stockholm, New Jersey (SNJ), and remote Cornwall, Connecticut observation sites used in the study. Map background is colored by urban (purple) to rural (green) gradient (Schiavina et al., 2023).



35 **Figure S2.** Time series of hourly methane (CH_4) observations used in the analysis categorized as city-scale (black) and local-scale (red) at the urban core ASRC site for January–May 2019–2024 (left to right, top to bottom).

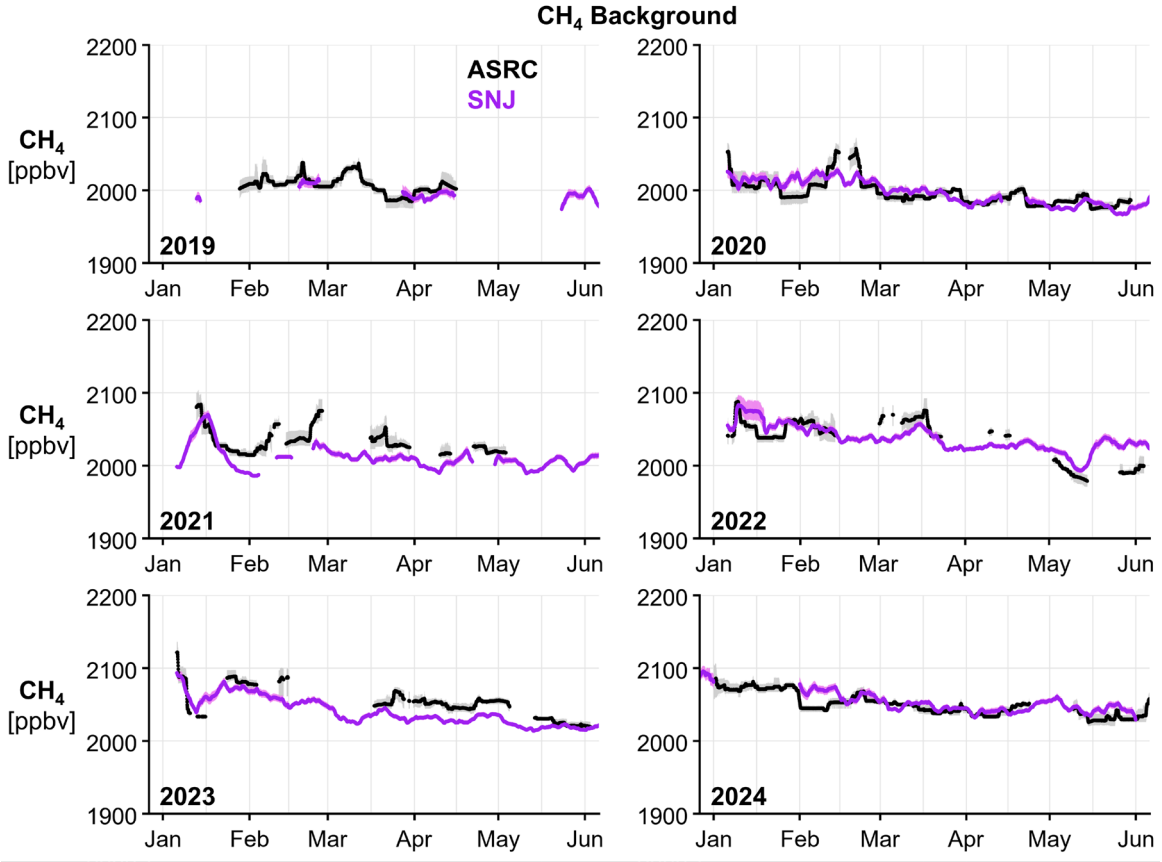


Figure S3. Timeseries of the methane (CH_4) backgrounds to the NYCMA for January–May 2019–2024 using the fifth-percentile method at the urban core ASRC site (black) and as the 10-day mean of observations at the remote Stockholm, New Jersey site (SNJ, purple). Shading shows the 95% confidence interval (CI) of the background.

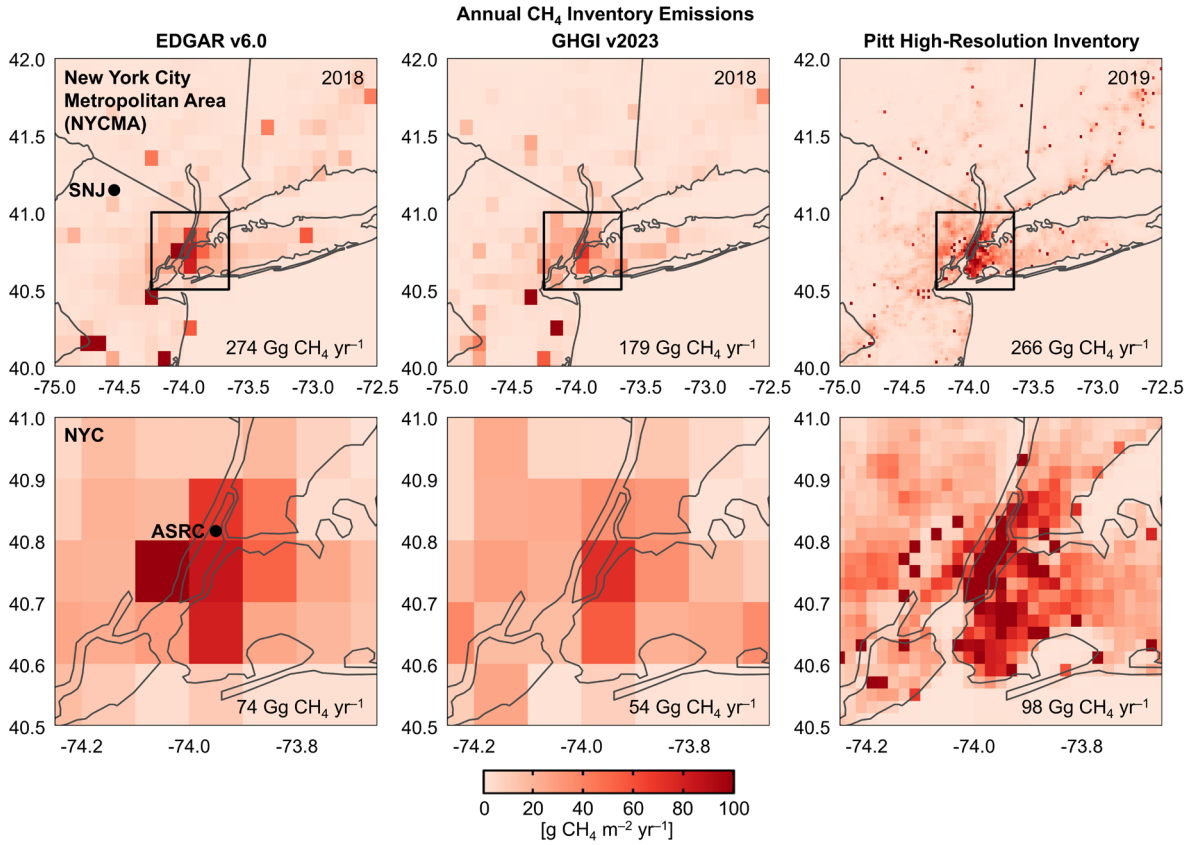


Figure S4. Maps of the annual mean methane (CH_4) emissions flux from various inventories for the NYCMA (top) domains and the locations of the urban core ASRC and remote SNJ observations sites used in the study. The annual total methane emissions for each domain and inventory combination are shown in the lower right. Methane emissions inventories are (left to right): Emissions Database for Global Atmospheric Research (EDGAR) v6.0 for 2018, EPA Greenhouse Gas Inventory (GHGI) v2023 for 2018 (Maasakkers et al., 2023), Pitt High-Resolution Inventory for 2019 (Pitt et al., 2024b).

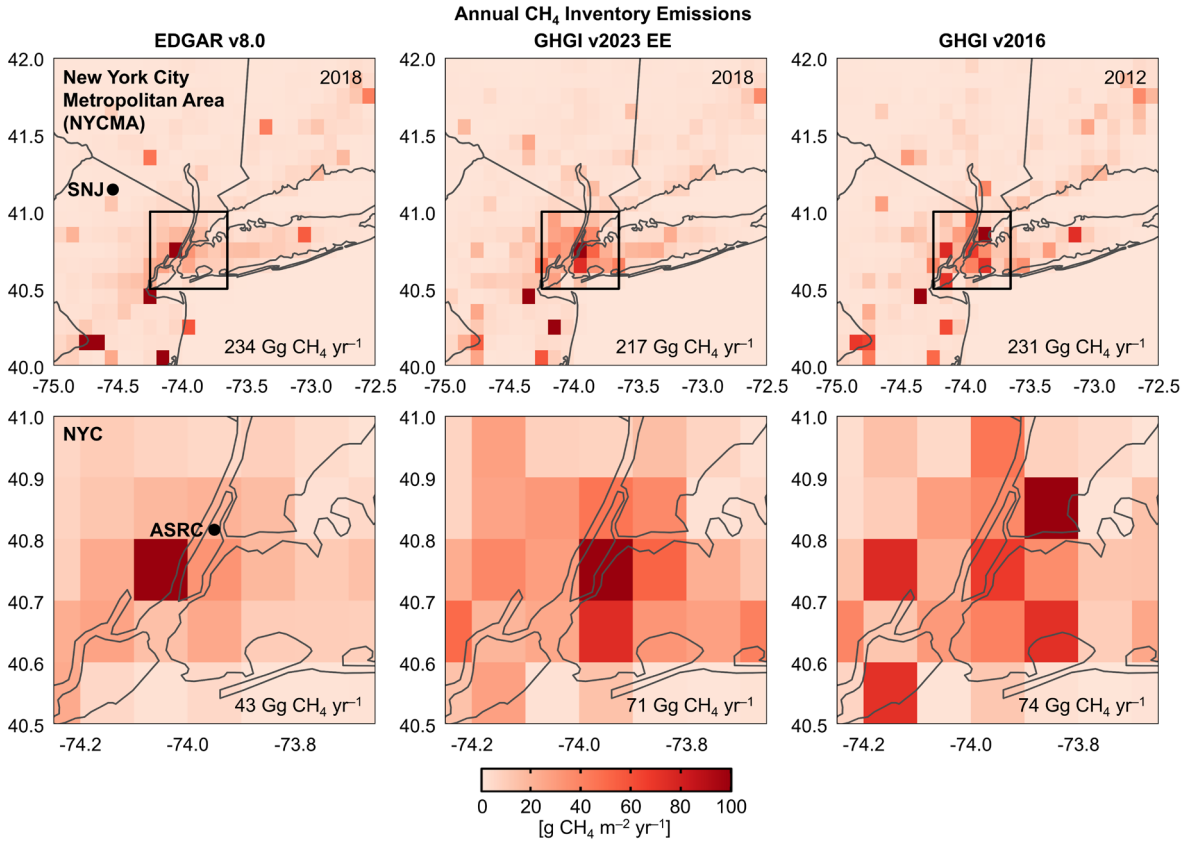


Figure S5. Maps of the annual mean methane (CH_4) inventory emissions as in Fig. S4. Methane emissions inventories are (left to right): EDGAR v8.0 for 2018, EPA GHGI v2023 with Express Extension (EE) for 2018 (Maasakkers et al., 2023), EPA GHGI v2016 for 2012 (Maasakkers et al., 2016).

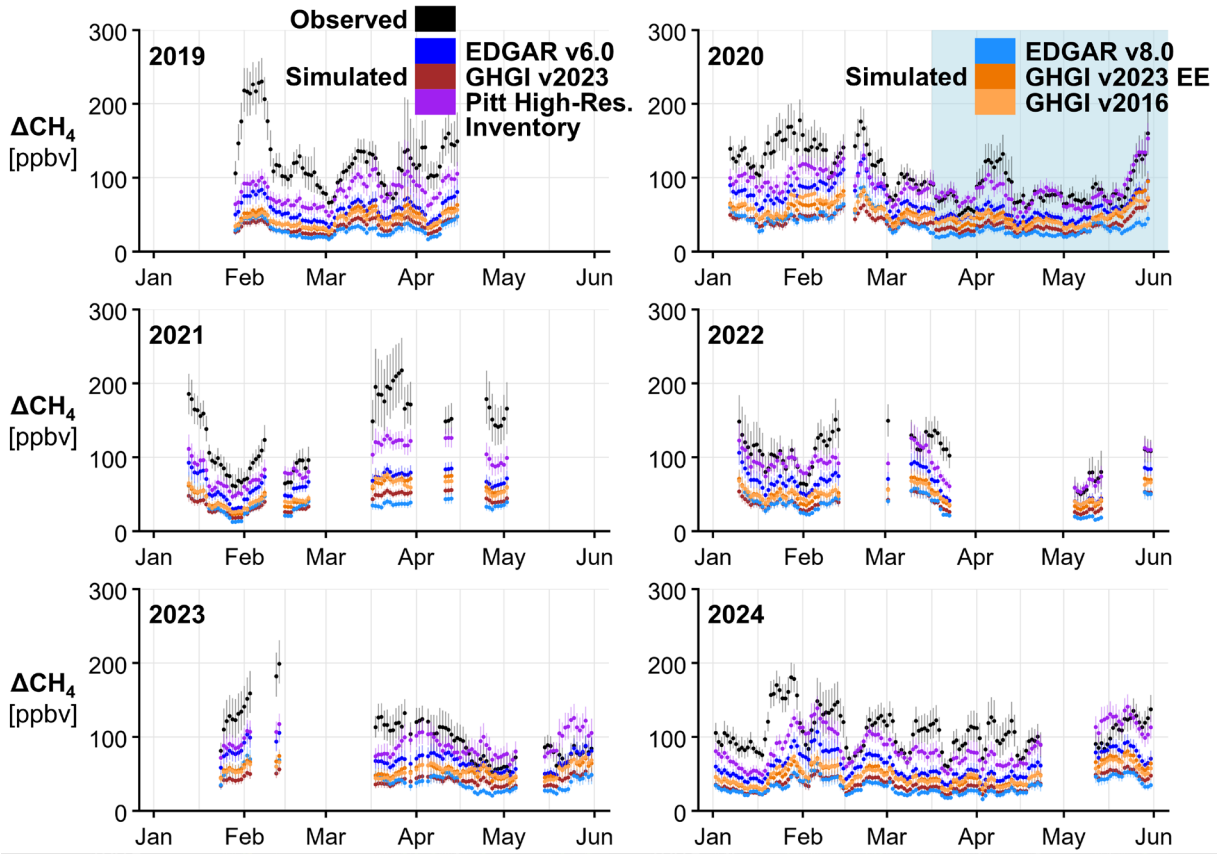


Figure S6. Timeseries of 10-day mean observed and simulated ΔCH_4 for the NYCMA domain as in Fig. 3. Additional simulated ΔCH_4 shown determined by HRRR-STILT combined with methane emissions from EDGAR v8.0 for 2018 (light blue), EPA GHGI v2023 with Express Extension (EE) for 2018 (Maasakkers et al., 2023) (orange), EPA GHGI v2016 for 2012 (Maasakkers et al., 2016) (tan).

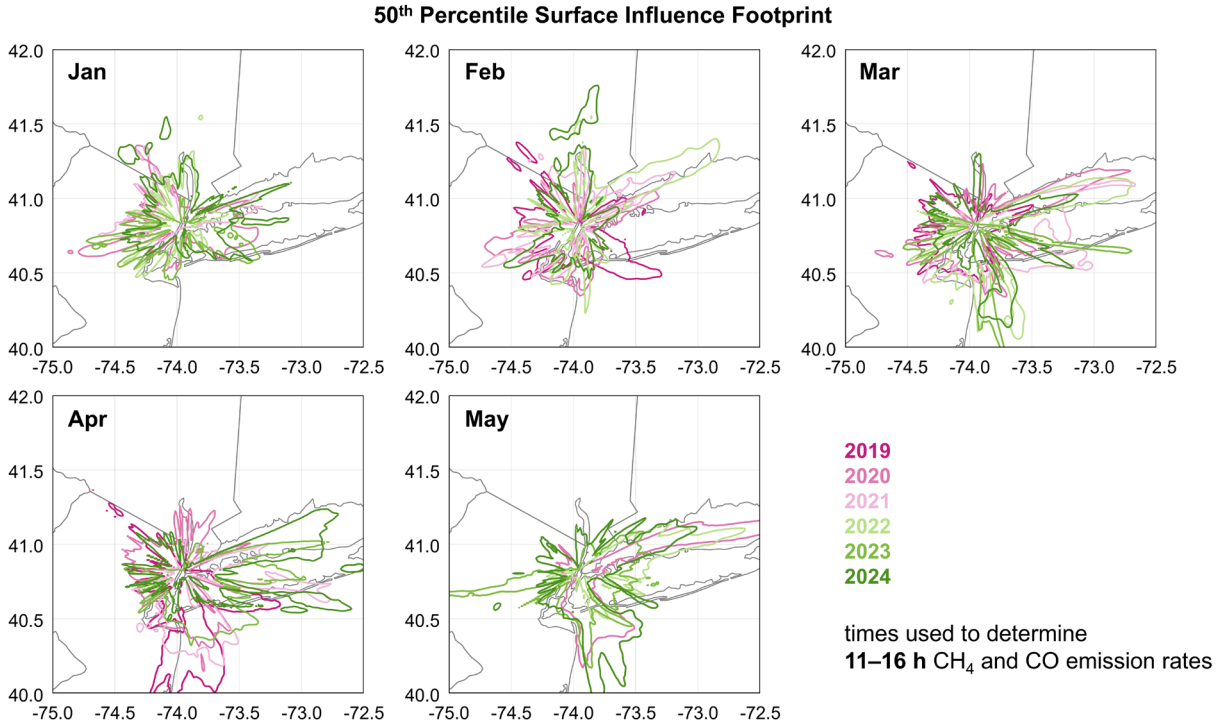


Figure S7. Contours of the 50th percentile mean surface influence footprint from HRRR-STILT used to calculate the afternoon (11–16 h) observed methane (CH_4) and CO emission rates from the NYCMA domain for January–May 2019–2024. Contours in each monthly panel are colored by year according to the legend. Individual months without enough data to meet availability threshold to calculate a monthly emission rate are not shown.

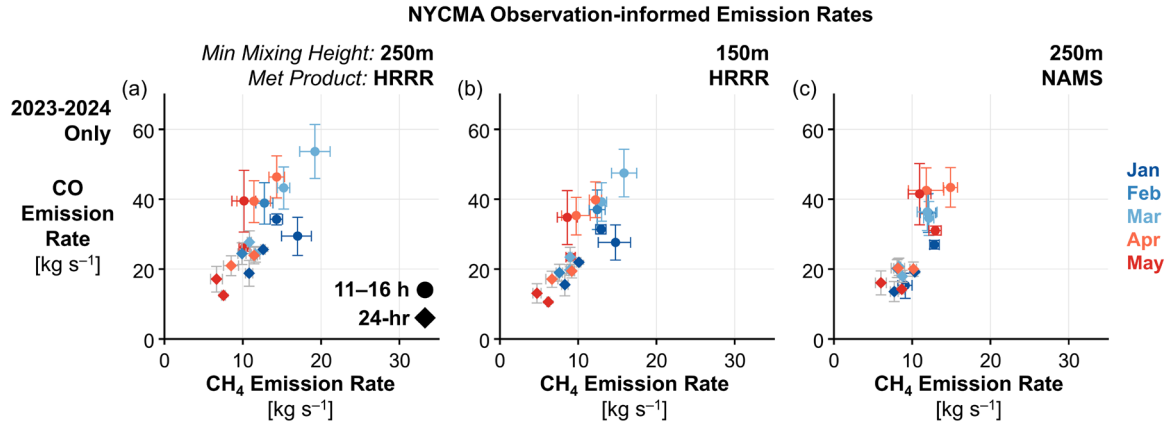


Figure S8. Comparison of monthly afternoon observation-informed methane (CH_4) and CO emission rates for the NYCMA domain as in Fig. 6c for only January–May 2023–2024 using STILT simulations with **(a)** a minimum mixing height of 250m and HRRR meteorology (study default), **(b)** a minimum mixing height of 150m and HRRR meteorology, and **(c)** a minimum mixing height of 250m and NAMS meteorology.

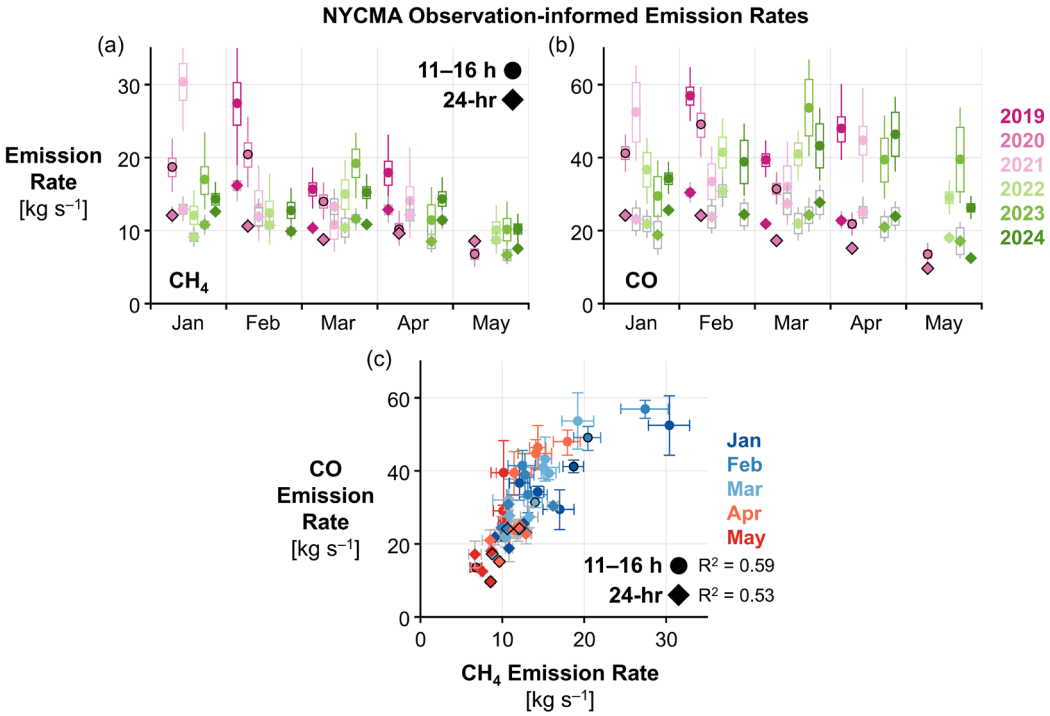


Figure S9. Observation-informed methane (CH_4) and CO emission rates from the NYCMA domain for January–May 2019–2024 as in as Figs. 6a–c (afternoon (11–16 h) rates, circles) but now including the 24-hr (diamonds) rates.

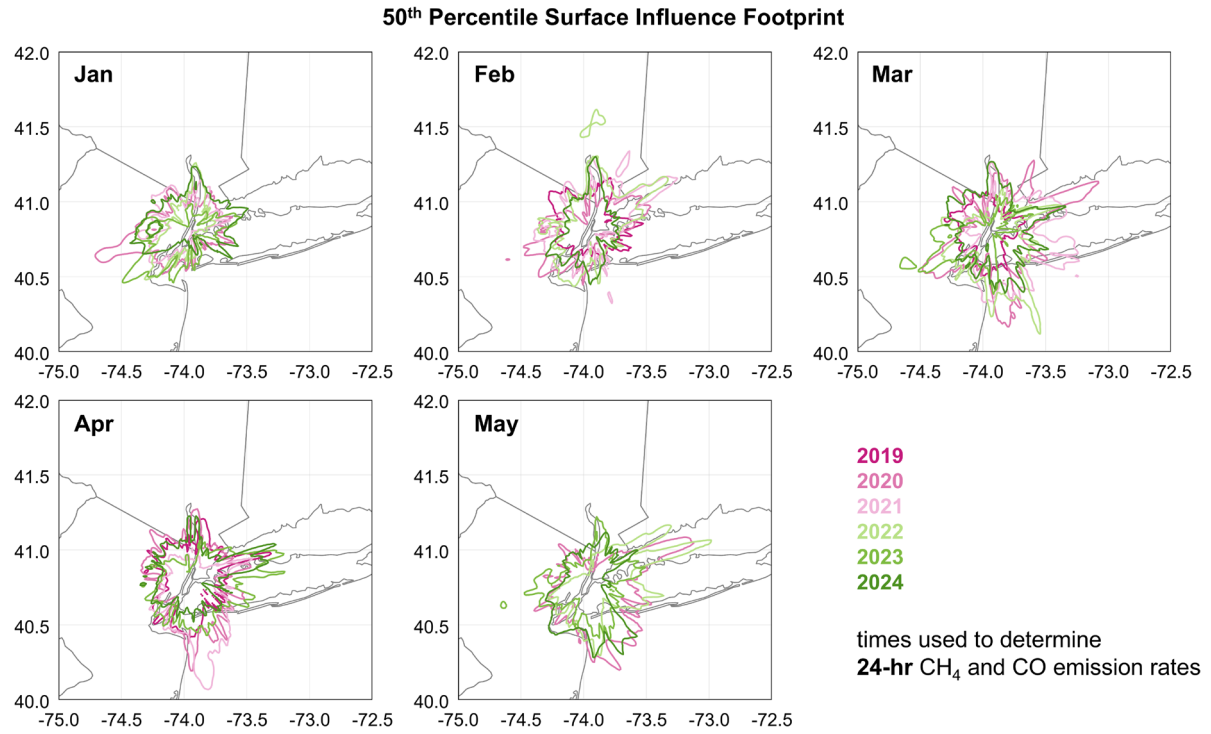


Figure S10. Contours of the 50th percentile mean surface influence footprint from HRRR-STILT as in Fig. S7 but now for the 24-hr observed methane (CH_4) and CO emission rates from the NYCMA domain for January–May 2019–2024.