

# ***Response to Reviewer #1***

We sincerely thank the reviewer for their valuable comments and suggestions to improve our manuscript. We have addressed all comments and included point-by-point responses below. Please note that the line numbers within this response relate to the clean submitted version of the manuscript.

Reviewer comments are highlighted in *black italic text*

Our written responses are shown in **bold blue text**

Current text in the manuscript is shown in **blue text**

Added text in the manuscript is shown in **red text**

## *Specific Comments*

***Point #1:*** [Page 5, lines 151–154] *In your discussion of the sensitivity study methods, the comparison between mean and median emission rates per common global grid cell may be unstable. In Region A, there are at most nine independently calculated emission rate estimates per grid cell, whereas in Region B there are at most three, with other regions falling somewhere in between. With sample sizes this small, estimates of either the mean or the median at the grid-cell level are inherently unstable, and the addition of a single new observation could dramatically alter the mean or median value of the grid cell emission rate. I would appreciate either further clarification of what this comparison is intended to demonstrate, or an exploration of an alternative approach. For example, you could perform a bootstrap analysis in which the common global grid-cell value is repeatedly sampled from the available emission estimates within each grid cell, and then show where the basin-wide mean- and median-based calculations fall within the basin-wide bootstrapped distribution (i.e., similar to the bootstrapping algorithms presented in Appendix B).*

**The reviewer is correct to point out that the aggregation of a small number of individual MethaneSAT scenes can produce unstable results at the grid-cell level, and we have taken several steps to explain this uncertainty. We add additional text to highlight that the aggregated MethaneSAT emissions products are not meant to be interpreted on a single cell basis since any single cell carries a large amount of uncertainty, but rather as parts of a larger sum, which in turn will reduce uncertainty in the estimates. We highlight this process and the proper interpretation of the aggregated MethaneSAT estimates in Sections 2.2 and 2.4, including newly added considerations for seasonal representativity. Single scene MethaneSAT estimates are calculated using 4,000 plausible emission estimates for every single emissions cell, from which the mean is used to represent the emissions for that single scene. We have clarified the text in the manuscript to better highlight this process**

As an additional test of sensitivity, we've calculated the resulting variation in the MethaneSAT emissions estimates after removing single scenes from the aggregation process, which offers some insight into the impacts of including new scenes to the aggregated emissions. The resulting sensitivity analysis finds a maximum change in emissions of +17% for the Amu Darya – TKM region, with an overall absolute average variation of 5% across all 33 scenes.

We believe that this new sensitivity analysis, in addition to further clarification in the main text that aggregated individual MethaneSAT scenes do not inherently represent annual emissions estimates, address the main concerns of the reviewer.

We have made the following changes in the main manuscript and SI:

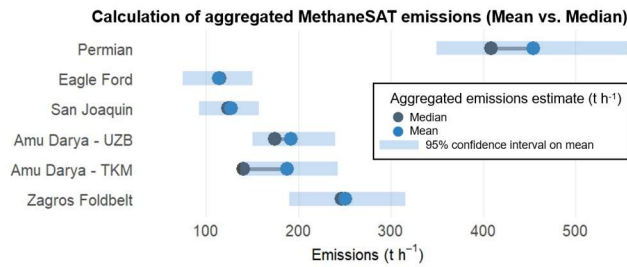
*Lines 145 – 151: "Individual MethaneSAT emissions estimates (i.e., a MethaneSAT scene or emissions map) represent methane emission estimates up to 28 hours back in time and vary in their spatial dimensions depending on the viewing geometry of the satellite. Nadir viewing observations produce up to ~220 km wide scenes while off-nadir observations produce up to ~440 km wide scenes. The MethaneSAT platform had an agile observing mechanism with off-nadir viewing at up to 40 degrees on one side of its observing track. We aggregate multiple MethaneSAT scenes together over the same regions to produce a spatially explicit estimate of methane emissions with increased temporal and spatial extents."*

*Lines 156 – 160: "We also test the sensitivity of MethaneSAT aggregated emissions estimates to the removal of single scenes and find that estimates are robust among the six regions (SI – Section 2, Fig. S12). We additionally consider any impacts from seasonal variability in our aggregated emissions estimates using 2022 monthly inversions data from TROPOMI (Pendergrass et al., 2025) to better compare to annual emissions estimates from top-down satellite inversions or bottom-up inventories (SI – Section 2)."*

*Lines 237 – 246: "Uncertainty in aggregated MethaneSAT emissions estimates is propagated using a Monte Carlo approach. Each emissions cell is represented by 4,000 samples drawn from its MCMC posterior distribution, reflecting mean-level uncertainty in the emissions estimate at that location. Where multiple emissions maps overlap a given cell, 4,000 combined cell-level estimates are generated by repeatedly drawing one value per map and averaging across maps. This Monte Carlo resampling procedure propagates uncertainty through the arithmetic mean without requiring assumptions about the functional form of the resulting distribution. This procedure is applied independently to all subregions defined by unique combinations of overlapping emissions maps (Fig. S2). Uncertainty on the total dispersed area emissions is the 95% confidence interval on the total across all samples (n = 4,000), with an additional 20% uncertainty added to account for assumed uncertainty in the static parameters in the input GFS weather data used for the inversions."*

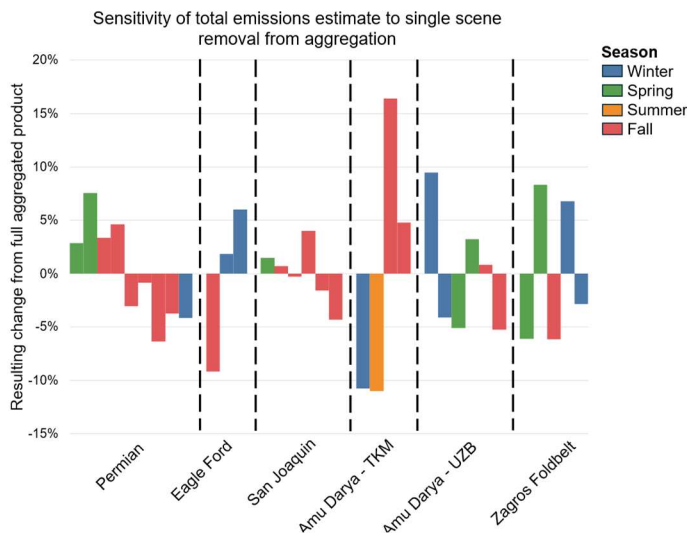
*Newly added section: SI - Section 2 "Aggregation of MethaneSAT scenes and seasonal variability"*

Newly added Fig. S10:



“Fig. S10: Differences in total methane emissions estimates after performing the aggregation of MethaneSAT scenes using the median or mean to calculate cell-level emissions from overlapping MethaneSAT scenes. Aggregated MethaneSAT total emissions are currently calculated using the mean for overlapping scenes. We find the largest difference between both approaches for the Amu Darya – TKM region, whereas the Zagros Foldbelt, San Joaquin, and Eagle Ford are relatively unchanged between approaches. Shaded blue bars represent the 95% confidence intervals of the current MethaneSAT aggregated estimates.”

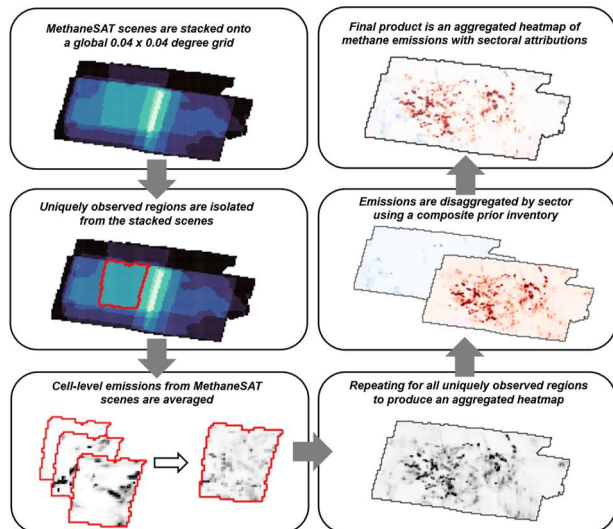
Newly added Fig. S12:



“Fig. S12: Resulting variation in MethaneSAT aggregated emissions estimates after single scenes from the aggregation process. The bars are colored according to the season from which the MethaneSAT observations were obtained. The percentage differences are calculated based on the same spatial domain since the removal of scenes can vary the extent of the aggregated output boundary.”

In addition, the text states that emission rates are being averaged per grid cell, a description that is also used in the caption of Figure S1. However, the label in the bottom-left panel of Figure S1 indicates that MethaneSAT observations are being averaged, rather than MethaneSAT regridded emissions. This discrepancy should be clarified. Furthermore, the figure does not specify what the error bars in Figure S1 represent.

We have corrected this instance and clarified language throughout the paper to differentiate observations versus the gridded methane emissions output from the inversion. We have also revised the in-figure text and caption of Fig. S1. We assume the reviewer was referring to Fig. S10 with regards to the error bars since there are none in Fig. S1. Our previous response addresses the lack of description for Fig. S10.



“Fig. S1: Diagram illustrating the methodology associated with the aggregation of multiple overlapping MethaneSAT emissions maps into a single regional estimate of methane emissions and the sectoral disaggregation of methane emissions derived from MethaneSAT observations.”

**Point #2:** [Page 6, lines 181-185] Here you describe the databases used as prior inputs for your regions and for non-oil and gas as well as oil and gas sources. While Figures S7 and S8 examine how varying the choice of prior database influences the sectoral attribution of emissions derived from MethaneSAT, a clearer explanation of how the specific combination of prior databases used for the final results was selected would be helpful. In particular, it would be useful to clarify how and why COMBO 26 in Figure S7 and COMBO 15 in Figure S8 were chosen as the final configurations.

We agree that our selection of bottom-up inventories used in our composite prior inventories are not adequately described or justified. We have added new sections in the main text and SI that further detail our selection process for the composite prior inventories, now noting that we optimize our selection based on guidance from a literature-based proportion of oil and gas emissions that incorporates satellite-based observations and combinations of bottom-up inventories that are methodologically distinct (if available).

We hope the following modifications address the reviewers points:

Lines 187-193: “For any region and sector, we combine emissions estimates from two bottom-up inventories with Carbon Mapper distinct point sources to produce the composite dataset. For regions within the US, we use the EPA-GHGI and EDGAR as inputs for non-oil and gas sources, and the EI-ME

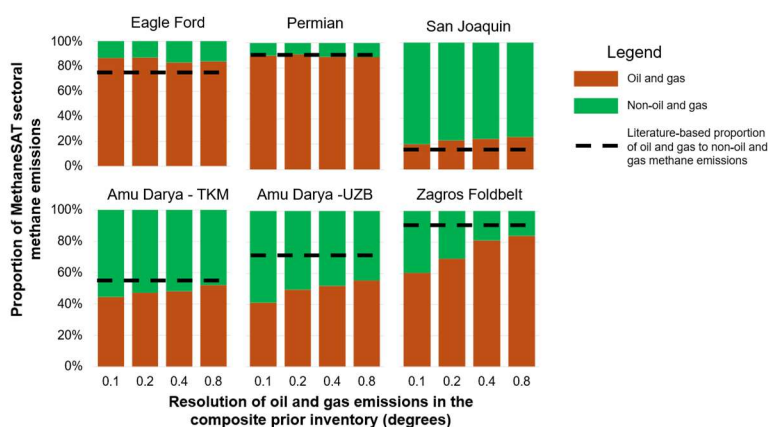
and EDGAR for oil and gas sources. For regions outside of the US, we use CAMS v6.2 and EDGAR as inputs for non-oil and gas sources, and the GFEI v2 and EDGAR as inputs for oil and gas sources. Other combinations of these bottom-up inventories, and their impacts on the resulting sectoral breakdown of emissions, are provided in the SI (Fig. S7; Fig. S8) with further explanation in the SI – Section 1.1.”

Lines 195-200: “To better account for regions where granular oil and gas infrastructure data is limited (i.e., regions outside of the US), we spatially aggregate oil and gas methane emissions estimates from the composite prior by a factor of four (i.e., from the native 0.1° x 0.1° resolution to 0.4° x 0.4°) while conserving the mass of emissions. A sensitivity test of this approach shows improved agreement in the sectoral proportions of emissions for non-US regions compared to a compilation of estimates from literature, while showing little to no improvement for regions in the US (SI – Section 1.2).”

Lines 623-626: “Sectoral attribution is applied as a post-inversion step using a composite prior inventory drawn from multiple spatially explicit datasets supplemented by global point source data from Carbon Mapper (2025). This approach improves sectoral allocation, especially for regions where information on oil and gas emissions data is sparse and information from one inventory can account for discrepancies in another (SI – Section 1.1, Fig. S5).”

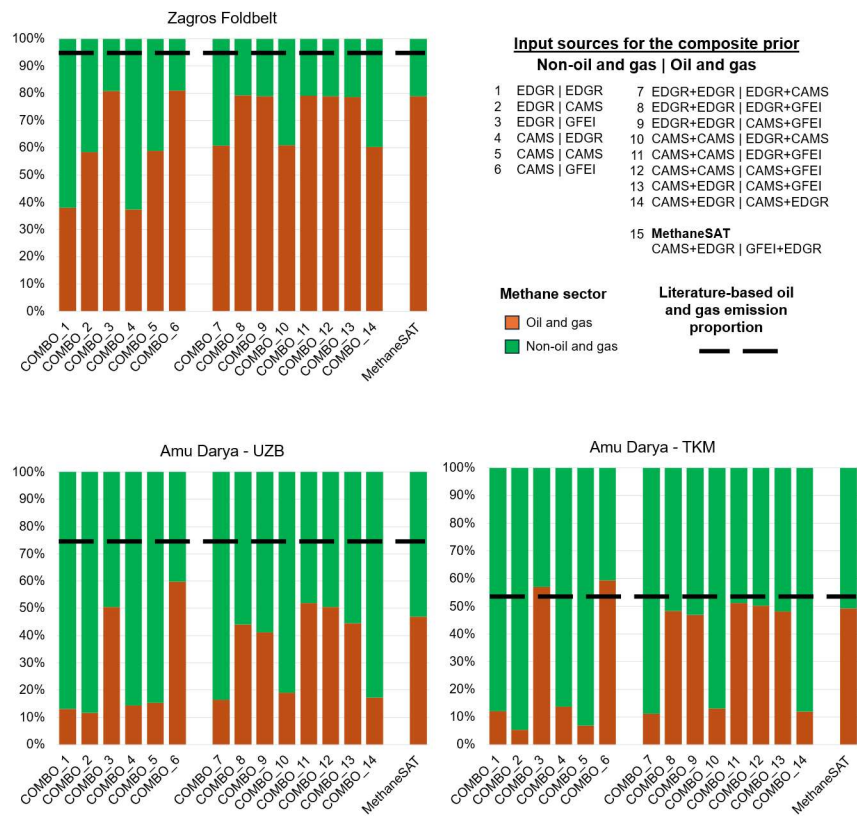
Newly added sections in SI: SI Section 1.1: “Selection of inventories used for composite prior” and SI Section 1.2 “Oil and gas estimates for non-US regions”

Revised Figure S6 in the SI:



“Fig. S6: Impacts of varying the resolution of the oil and gas sectoral emissions from the composite prior inventory used to disaggregate methane emissions estimates from MethaneSAT. Results of the sensitivity test for all six regions are shown. The dashed black line indicates the literature-based proportion of oil and gas to non-oil and gas methane emissions in the six regions. For the US regions (top row), the chosen resolution used for sectoral disaggregation is 0.1 degrees. For non-US regions (bottom row), we use a resolution of 0.4 degrees.”

Revised Figure S7 and S8 in the SI:



“Fig. S8: Impacts of varying the input data used in the stacked prior inventory to disaggregate methane emissions from the MethaneSAT observations for regions outside of the US. The impacts of the inclusion of Carbon Mapper point sources are also not shown. The dashed black line indicates the literature-based proportion of oil and gas to non-oil and gas methane emissions in the six regions.”

**New Table S4 in the SI:**

“Table S4: Studies and data sources used in the calculation of a literature-based proportion of oil and gas emissions which is explained in the SI Sections 1 and 2. Also indicated in the table is the respective name for the spatially-explicit methane emissions estimate (if applicable), a broad descriptor of the methodology used to obtain the methane emission estimate, a breakdown of the methane sectors included in the estimate, and the latest year represented within the dataset.”

Study	Data source name	Method	Sectors included	Latest year
(Maasackers et al., 2023)	EPA-GHGI	Bottom-up	All	2018
(Omara et al., 2024)	EIME	Bottom-up	Oil and gas	2023
(Granier et al., 2019)	CAMS v6.2	Bottom-up	All	2024
(Crippa et al., 2024)	EDGAR_GHG_2025	Bottom-up	All	2024
(Scarpelli et al., 2022)	GFEI v2	Bottom-up	Oil and gas, coal	2019

(East et al., 2025)	-	TROPOMI	All	2023
(Shen et al., 2023)	-	TROPOMI	Oil and gas, coal	2019
(Worden et al., 2022)	-	GOSAT	All	2019
(Lu et al., 2023)	-	GOSAT	All	2019
(Nesser et al., 2024)	-	TROPOMI	All	2019

New Table S5 in the SI:

“Table S5: Literature-based estimates of oil and gas and non-oil and gas emissions within the spatial domains of all six regions. The resulting proportions are used to inform the selection process of inputs used for the composite prior, and to support the use of decreasing the resolution of bottom-up inventories.”

Region	Literature-based oil and gas estimate (t/h)	Literature-based non-oil and gas estimate (t/h)	Literature-based proportion of emissions (oil and gas / non-oil and gas)
Eagle Ford	46.9	14.4	77 / 23
Permian	290	23.8	92 / 8
San Joaquin	16.1	82.7	16 / 84
Amu Darya - TKM	57.9	48.6	54 / 46
Amu Darya - UZB	94.4	32.4	74 / 26
Zagros Foldbelt	310	16.0	95 / 5

**Point #3:** [Page 7, lines 217-218] You state that an assumed methane composition of 80% in natural gas was used for all intensity metric calculations. Did you perform a sensitivity analysis to assess how varying this assumed methane concentration affects the resulting intensity estimates? In addition, are there datasets or studies that could be used to sample basin specific methane concentrations in natural gas? For example, Burdeau et al. [2025] provide basin-level produced gas composition estimates for two of the U.S. basins included in your study, albeit for a slightly earlier timeframe.

Since we use methane composition in the denominator of our gas-normalized intensity computations for our team’s analyses, the intensity scales inversely with the methane composition. The changes in intensity are dependent on the ratio of differing methane compositions, not the percentage change in the composition. For the 80% -> 70% change in composition assumption example, which is a 12.5% decrease in the composition estimate, the increase in the intensity estimate would be 14.3% (0.8/0.7).

The energy-normalized intensity is unaffected by the methane composition assumption, since it’s not used in any part of the computation for this metric, which we now highlight in the manuscript.

If we use the applicable basin-specific composition estimates from Burdeau et al. 2025, the gas-normalized intensity increases from 2.6% to 2.9% for the Permian Basin (71.5% CH<sub>4</sub> comp assumption) and from 12.1% to 16.5% in the San Joaquin Basin (58.6% CH<sub>4</sub> composition assumption). So the absolute change for the Permian Basin would be 0.3%, and the percent change relative to the original estimate is +11.9%. For the San Joaquin Basin, the absolute change is 4.4%, and the relative change is +36.6%. The energy-normalized intensities would remain unchanged. To account for the other regions, we use gas compositions from US basins presented in Burdeau et al. (2025) that have comparable fluid production (ie., gas-dominant, oil-dominant, mixed production) to calculate adjusted loss rate metrics. We hope these following changes address the main concerns of the reviewer:

Lines 225-231: “We assume a methane gas composition in natural gas of 80% for loss rate calculations. Assumptions on the methane gas composition directly impact the resulting loss rate calculations and scale inversely to increasing gas composition. We test the sensitivity of our loss rate estimates using methane gas composition values from spatially-explicit estimates for the US (Burdeau et al., 2025) and approximate gas compositions for non-US regions using US basins with similar fluid production characteristics (Table S7). Energy intensity metrics do not incorporate assumptions of methane gas composition into their calculations and are therefore unaffected.”

New Table S7 in the SI:

“Table S7: Sensitivity of methane loss rate calculations using assumptions of methane gas composition based on spatially-explicit estimates from Burdeau et al. (2025) for the US. For non-US regions, we choose methane compositions that reflect the fluid production of the basins. For Amu Darya -TKM/UZB, we assume the same methane gas composition as the Appalachian basin (i.e., over 95% of production from gas). For the Zagros Foldbelt, we assume the same gas composition as the San Joaquin. For the Eagle Ford, we use the gas composition provided for the Gulf Coast (Burdeau et al., 2025).”

Region	MethaneSAT loss rates [95% c.i.]	Assumed methane gas composition	Adjusted methane gas composition	Adjusted MethaneSAT loss rate [95% c.i.]
Eagle Ford	2.4% [1.4 – 3.4%]	0.80	0.79	2.4% [1.4 – 3.4%]
Permian	2.6% [1.9 – 3.5%]	0.80	0.72	2.9% [2.1 – 3.9%]
San Joaquin	12.1% [8.9 – 16.0%]	0.80	0.59	16.5% [12.2 – 21.8%]
Amu Darya - TKM	2.9% [2.1 – 3.7%]	0.80	0.90	2.6% [1.9 – 3.3%]
Amu Darya - UZB	3.7% [2.7 – 5.0%]	0.80	0.90	3.3% [2.4 – 4.5%]
Zagros Foldbelt	18.6% [13.4 – 23.8%]	0.80	0.59	25.4% [18.3 – 32.5%]

**Point #4:** [Page 17, lines 491-496] You note that MethaneSAT underestimates methane emissions relative to EDGAR for the Amu Darya and Zagros Foldbelt basins, shown in Figure 6. Could you elaborate on potential reasons for this discrepancy? At present, no discussion is provided. In addition, on line 496 you reference Figure 7 when discussing this underestimation relative to EDGAR; however, there are only six figures, and this appears to be a reference to Figure 6.

EDGAR employs a “bottom-up” inventory methodology in which total methane emissions are estimated by applying emission factors (e.g., methane emissions per unit of oil production) to corresponding activity data (e.g., total oil output). This methodology follows the guidelines of the Intergovernmental Panel on Climate Change (IPCC) and incorporates country-specific oil and gas methane emission factors based in part on the IPCC Tier 1 default values, thereby ensuring consistency, completeness, and comparability across countries (<https://edgar.jrc.ec.europa.eu/methodology>). The Tier 1 default emission factors generally assume higher methane intensities for oil systems—including venting, fugitive emissions, and flaring—than for gas systems (see [https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2\\_Volume2/V2\\_4\\_Ch4\\_Fugitive\\_Emissions.pdf](https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_4_Ch4_Fugitive_Emissions.pdf)). As a result, methane emissions may be overestimated in regions dominated by oil production when regional conditions and technological characteristics—such as high-efficiency flaring, frequent leak detection and repair, and advanced methane capture systems—are not adequately represented. Consistent with this interpretation, recent studies have reported comparatively higher EDGAR methane emission estimates for oil systems (e.g., Scarpelli et al., 2025; <https://doi.org/10.5194/essd-17-7019-2025>).

We have added new text in the Results to briefly highlight the reason for this difference to Edgar, and have also corrected Figure labels within the main text.

*Lines 567 – 571:* “Across districts in the Zagros Foldbelt region we find consistent agreement, and even underestimation, of methane emissions from MethaneSAT compared to EDGAR (Fig. 6). In Iran, top-down inversion studies have reported methane emissions lower than EDGAR and closer to UNFCCC inventories (Maasackers et al., 2019), with discrepancies likely arising in part from differences in the representation of oil and gas emissions and EDGAR’s use of generalized emission factors (Crippa et al., 2024).”

For Figure 1, I found the tick label font size and inset text font size to be a bit small and blurry. Please ensure the final figures are clear.

**Figure 1 has been replaced with a high-resolution version**

I believe Figure 4 is missing a legend to indicate which part of the bars represent oil and gas vs. non-oil and gas emissions. If following could be the non-oil and gas emissions, but this is not indicated in Figure 4.

**Legend has been added to clarify a similar oil/gas versus non-oil/gas breakdown for the figure**

*Page 2, line 52, I think a citation to Veefkind et. al. 2012 for when you introduce TROPOMI would be nice here for completeness.*

**Agreed – we have added the citation to the relevant section**

*Online 64, page 2, you need to remove the period after “(i.e., 220 × 440 km<sup>2</sup>)”.*

**Period has been removed**

*Page 3, line 79, I believe there is a placeholder “refer to Zhan et. al. 2020” that made it into the final preprint. I believe there should just be a citation to Zhang (not Zhan) et. al. 2020 here.*

**Placeholder removed and replaced with correct citation**

*Page 3, line 85, you’ve got another placeholder for citing Shen et. al. 2022, ACP still in here.*

**Placeholder removed and replaced with correct citation**

*Another placeholder citation on Page 3, Line 88.*

**Placeholder removed and replaced with correct citation**

*For Figures S3 and S4, the current captions refer to “Sentinel-5P” as the source of SRON-TROPOMI super-emitter detections. For clarity, these should identify that the TROPOMI instrument on the Sentinel-5P satellite provides the methane observations from which plume detections are derived. Moreover, please include formal references and citations for all datasets used in all panels of these figures.*

**Captions of Figures S3 and S4 adjusted to correctly reference the instruments used for the methane plume detections. We have also included formal references for all the point source imagers in the figure.**

*There are grammatical and typographical errors in the manuscript that need to be addressed before the article is published, but did not hinder the review process.*

**We have reviewed the manuscript for typographical and grammatical errors**

