Reply to comments on "Toward a versatile spaceborne architecture for immediate monitoring of the global methane pledge" by Yuchen Wang et al.

Reply to Reviewer #1:

This paper proposes an interesting method to address the important issue of quantifying current methane emissions. The authors justifiably argue that no current satellite instrument provides both the coverage and the spatial resolution to accurately measure global methane concentrations; to address this lack they propose a two-step method that uses data from two very different instruments: the wide swath, coarse spatial resolution TROPOMI and narrow swath but very high spatial resolution PRISMA. The TROPOMI data are used to locate high methane emission regions and the methane hotspots within these regions, then the co-located PRISMA data are examined for the presence of plumes. Emissions over the hotspots and plumes are estimated by combining wind speed information with an integrated mass enhancement model.

The approach is demonstrated for short periods over five small regions and the results are compared with surveys over two other regions. The median and range of the plume emissions are qualitatively consistent with those obtained using data from another (non-specified) satellite instrument over the Permian basin, and much higher than those from an aircraft campaign over California. The hotspot and plume emissions are also compared with emissions from the EDGAR_v6.0 inventory; the hotspot emissions were somewhat consistent with the inventory, while the plume emissions were much higher.

Summarizing the above, this is an interesting method with very interesting results. The authors evidently put a great deal of effort and enthusiasm into this work. However, the paper presents several problems, principally lack of detail on how some of the results were obtained. I have listed the main technical issues below, which need to be addressed before the paper can be published. An overarching issue is English language usage. Verb tenses are frequently used incorrectly (e.g, past or conditional future for present), and nouns and adjectives are interchanged. Before resubmitting the authors should have either a native English speaker or someone with excellent English revise the paper. I will be happy to provide more specific wording changes once this been done, if they are still necessary.

Response: We truly appreciate these positive responses and thorough summarizations. We are also very grateful for the valuable comments and suggestions and have addressed all of them in our revised manuscript. Particularly, we have supplemented more technical details to clarify the procedure of our framework. In addition, our co-authors (involving native English speakers) have carefully gone through the entire manuscript to improve the English level.

The followings are our point-to-point responses to the reviewer's comments. The responses are shown in brown font, while the added/rewritten parts are presented in blue font. All revised figures and tables are also included in the manuscripts.

1. The method for identifying high emission areas and plumes appears to be visual identification. The authors do mention a Boolean mask for identifying the former, but no details are provided and the reader is left wondering what this means. This needs to be clarified. Such an intensive method is feasible for a small analysis, such as presented in figures 1-3, but obviously not for long term, global emission estimates. Here the authors suggest a machine learning approach for further applications of their method, which is a reasonable suggestion. However, this issue makes the year long results presented in S3 and S4 questionable. Were the TROPOMI maps obtained by applying the Sun oversampling method for an entire year over the original methane concentrations? If so which wind fields were used to obtain the emissions, both for the regional and plume estimates? How were the PRISMA data averaged over the year? Given the variability in wind direction, I don't think it makes sense to look for plumes in averaged data. These plots need to either explained in much greater detail, or omitted entirely from the paper. If they are to be included, then the authors need to be clear which results (short term or annual) are used in all other plots.

Response: Thank you for these valuable comments and suggestions. First, we have supplemented more technical details to clarify the role of the Boolean mask method. As you pointed out, in the first tier of our framework, we apply visual inspection to identify methane hotspots using the TROPOMI-based methane retrievals. The transformation from visual inspection to automatic recognition would significantly advance long-term, global methane monitoring. However, no satisfactory set of criteria is found that could be suitable for this study. This was mainly because, in localized regions, methane budgets respond to the changes in not only super-emitters but also complex external factors (e.g., meteorology, topography, and background concentrations). Similar compromises are also adopted in previous studies. Therefore, automatic recognition enabled by artificial intelligence would play an essential role in the versatile spaceborne architecture for long-term, global methane monitoring (Ouerghi et al., 2021; Paoletti et al., 2018; Yang et al., 2018; Yu et al., 2017; Zhang et al., 2018).

Regarding the identified methane hotspots, we utilize a Boolean mask to select plume-influenced pixels downwind of the source. The background distribution (mean ± standard deviation) is defined by an upwind sample of the measured columns, in which the hourly wind field data came from the ERA5 reanalysis dataset produced by the European Centre for Medium-Range Weather Forecasts (ECMWF) (Hoffmann et al., 2019). We then sample the surrounding (5 × 5) pixels centred on each pixel and compare the corresponding distributions to the background distribution based on a Student's t-test. Pixels with a distribution substantially higher than the background at a confidence level of 95% are assigned to the plume. More details in the Boolean plume mask can be found in previous studies (Pandey et al., 2019; Varon et al., 2018).

Second, we agree that it might make no sense to look for plumes in averaged data due to the variable wind direction and have thus omitted the oversampled methane maps in the first tier of our framework (Fig. S3). In turn, using year-round snapshots in the second tier of our framework, we inspect the identified super-emitters (Figs. 1b ~ 1g) repeatedly and find more methane plumes as expected (Fig. S4). This reinforces the above hypothesis for the widespread occurrence of methane super-emitters.

Added/rewritten part in Sect. 2.3: In the first tier of our framework, we apply visual inspection to identify methane hotspots using the TROPOMI-based methane retrievals. The transformation from visual inspection to automatic recognition would significantly advance long-term, global methane monitoring. However, no satisfactory set of criteria is found that could be suitable for this study. This was mainly because, in localized regions, methane budgets respond to the changes in not only super-emitters but also complex external factors (e.g., meteorology, topography, and background concentrations). Similar compromises are also adopted in previous studies. Therefore, automatic recognition enabled by artificial intelligence would play an essential role in the versatile spaceborne architecture for long-term, global methane monitoring (Ouerghi et al., 2021; Paoletti et al., 2018; Yang et al., 2018; Yu et al., 2017; Zhang et al., 2018).

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Added/rewritten part in Sect. 3.2: To further explore such a hypothesis, we extend the temporal sample window of our multi-tiered framework. Using year-round snapshots in the second tier of our framework, we inspect the identified super-emitters (Figs. 1b ~ 1g) repeatedly and find more methane plumes as expected (Fig. S3). This reinforces the above hypothesis for the widespread occurrence of methane super-emitters.

2. The plume maps would be more interesting if the plume source were clearly marked.

Response: Thanks. We have marked all the plume sources in Fig. 1 and Fig. S3.

3. How was the background vector used in equation 1 derived?

Response: Thanks. We have supplemented brief descriptions for this issue. The $\vec{\mu}$ and Σ represent the mean background radiance and corresponding covariance, respectively, calculated with their common formulas after subtracting the current signal estimates from the data. Specifically, the $\vec{\mu}$ is calculated from the data with the removal of the most recent enhancement estimates, while the Σ is then calculated with updated $\vec{\mu}$ and the most recent enhancement estimates. More technical details are reported in previous studies (Foote et al., 2020). Note that, owing to the non-uniform response of individual detectors in PRISMA, they are calculated based on per-column spectrums in order to consider different responses of across-track detectors to radiance.

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4. What does this sentence mean: methane enhancements detected in spectrometers generally exhibit sparsity, especially over low albedo surfaces.

Response: Sorry for the confusion we caused. We have revised this sentence to clarify this issue. In principle, it would be more difficult to detect methane enhancements in pixels over low-albedo surfaces. Although methane absorption is independent of albedo, the resulting signal in absolute radiance is weakened with surface albedo decreasing.

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5. Please define the co-location criteria between the TROPOMI and PRISMA datasets.

Response: Thanks. We have supplemented the definition the co-location criteria between the TROPOMI and PRISMA datasets. Regarding the identified regional hotspots, we also apply visual inspection to search for plumes within their surrounding 30 km scales (i.e., corresponding to the swath width of PRISMA) in the second tier of our framework.

Added/rewritten part in Sect. 2.3: Regarding the identified regional hotspots, we also apply visual inspection to search for plumes within their surrounding 30 km scales (i.e., corresponding to the swath width of PRISMA) in the second tier of our framework (Irakulis-Loitxate et al., 2021; Lauvaux et al., 2022; Martin et al., 2018; Varon et al., 2020).

6. The section on comparing the TROPOMI/PRISMA results with the California and Permian surveys needs to provide more detail on those surveys (instrument, time of year, temporal and spatial extent). It also needs to emphasize that these comparisons are basically tests of reasonableness, not true quantitative comparisons.

Response: Thanks. We have supplemented more technical details on these surveys. The California survey aims to provide the first view of methane super-emitters across the state. This survey is conducted with the Next Generation Airborne Visible/Infrared Imaging Spectrometer (AVIRIS-NG), with 5 nm SWIR spectral sampling, 1.8 km view field, 3 m horizontal resolution, and 3 km cruise altitude, and contains five campaigns over several months from 2016 to 2018. Moreover, this instrument is unique due to its high signal-to-noise ratio and is capable of characterizing methane super-emitters with emissions as small as 2 ~ 10 kg/h for typical surface winds of 5 m/s.

The Permian survey takes advantage of imaging spectroscopy technologies to provide the first spaceborne region-scale and high-resolution survey of methane super-emitters in the Permian basin. This survey is acquired by 30 hyperspectral images from three satellite missions, including Gaofen-5, ZY1, and PRISMA, and focuses on an area of roughly 200 × 150 km^2 in the Delaware sub-basin of the Permian basin within several days (mostly on four different dates: 15 May 2019, 1 November 2019, 29 December 2019, and 8 February 2020). More technical details on these two surveys can be found in previous studies (Duren et al., 2019; Irakulis-Loitxate et al., 2021).

Moreover, we agree that such comparisons are basically reasonableness test rather than stringently quantitative validations due to measurement divergencies between these datasets (e.g., spatial resolution and detection limit). Collectively, although such comparisons are not quantitative comparisons due to measurement divergencies between these datasets (e.g., spatial resolution and detection limit), they offer further context for the emission magnitude of the identified methane super-emitters and indicate the outstanding strength of our results that could be analogous to abundant outcomes from field campaigns. More importantly, this highlights the urgent need for global monitoring of 'nameless' O&G facilities that possibly emit methane as much as the California field and Permian basin.

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7. The phrase "on a per column basis" is frequently used: what does this mean?

Response: Sorry for the confusion we caused. We have supplemented some sentences to explain this phrase at its first appearance. The matched-filter algorithm focuses on the individual columns rather than the whole scene to resolve methane enhancements. This means that the methane enhancement per column is calculated separately (i.e., methane enhancements were calculated on a per-column basis). More explanations can be found in Guanter et al. (2021).

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8. The detailed uncertainty analysis is confusing, disorganized and hard to follow. Please put some more thought in how to present this information.

Response: Thank you very much for this constructive suggestion. We have reorganized and revised the detailed uncertainty analysis in Supplementary Information to clarify this issue, which has been explicitly divided into three sub-issues: (1) uncertainties in the PRISMA-based methane retrievals; (2) uncertainties in the TROPOMI-based methane emission estimates; and (3) uncertainties in PRISMA-based methane emission estimates. Note that operational TROPOMI-based methane retrieval products have been evaluated strictly and proved to be reliable globally (except in low- and high-albedo and snow-covered areas) (Lorente et al., 2021; Sha et al., 2021) and the related uncertainty analysis is thus omitted here. As a result, we could confirm the reliable performance of our framework. Comprehensive uncertainty analysis is illustrated in Supplementary Information.

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Reply to comments on “Toward a versatile spaceborne architecture for immediate monitoring of the global methane pledge” by Yuchen Wang et al.

Reply to Reviewer #2:

This paper aims at proposing a framework to utilize current space-borne methane observations to monitor regional emission hotspots and qualify super emitters. The framework combines two methods: one based on global mapping using TROPOMI and the other based on PRISMA (or other high-resolution mappings for small target areas). However, it is not clear what makes this framework different from previous studies (many are cited here), and it is suggested that the authors should clearly state the novel aspects of their method.

Response: We truly appreciate this valuable suggestion. We have revised related sentences and supplemented clear statements for the novel aspects of their method. Collectively, existing studies still struggle to surveillance global methane super-emitters due to the fact that individual satellite missions, either TROPOIM or PRISMA, cannot coordinate large-scale swath and high-resolution sampling. To address this issue, we present a two-tiered, space-based framework that coordinates TROPOIM and PRISMA for both planet-scale and plant-level methane retrievals.

Added/rewritten part in Sect. 1: Collectively, existing studies still struggle to surveillance global methane super-emitters due to the fact that individual satellite missions, either TROPOIM or PRISMA, cannot coordinate large-scale swath and high-resolution sampling. To address this issue, we present a two-tiered, space-based framework that coordinates TROPOIM and PRISMA for both planet-scale and plant-level methane retrievals.

Additionally, the approach is only demonstrated over short periods for five small areas, and the results are well compared with previous studies. The method for identifying high emission areas and plumes appears to be “visual inspection”, which raises questions about how this "framework" could scale to "immediate monitoring of the global methane." This is a key point that needs to be addressed for “a versatile spaceborne architecture.” Besides, the detection limit of this method and how it deals with hotspots from natural sources or other anthropogenic sectors other than oil and gas (landfill, agriculture) should be better illustrated before the paper is considered for publication.

Response: Thanks for these insightful comments. Yes, we applied visual inspection to identify methane hotspots and plumes using the TROPOMI-based and PRISMA-based methane retrievals. We agree that “visual inspection” is one of the key obstacles to realizing long-term, global methane monitoring. First, we have revised the title to clarify the existing gap to a versatile spaceborne architecture. Second, we have further explained the key role of automatic recognition in long-term, global methane monitoring. The transformation from visual inspection to automatic recognition would significantly advance long-term, global methane monitoring. However, no satisfactory set of automatic criteria is found that could be suitable for this study. This is mainly because, in localized regions, methane budgets respond to the changes in not only super-emitters but also complex external factors (e.g., meteorology, topography, and background concentrations). Similar compromises are also adopted in previous studies. Therefore, automatic recognition enabled by artificial intelligence would play an essential role in the versatile spaceborne architecture for long-term, global methane monitoring (Ouerghi et al., 2021; Paoletti et al., 2018; Yang et al., 2018; Yu et al., 2017; Zhang et al., 2018).

Besides, the detection limit of this framework depends mainly on the TROPOMI-based and PRISMA-based methane retrievals, which have been well discussed in previous studies (Guanter et al., 2021; Hu et al., 2018). Here we have thus supplemented associated discussions on this detection limit briefly. As the robust relationship between the "minimum source" and the related methane enhancement interpreted by Jacob et al. (2016) and Guanter et al. (2021), the detection threshold for the TROPOMI instrument is 4000 kg/h with a wind speed of 5 km/h. Following the same relationship in the PRISMA instrument, we estimate that a retrieval precision of 114 ppb (6.1% with the assumed background concentration of 1850 ppb), such as in the case of the Hassi Messaoud site (Fig. S10e1), would lead to a detection limit of 800 kg/h for the same wind speed (analogous to the reported range of 500 ~ 900 kg/h) (Guanter et al., 2021; Irakulis-Loitxate et al., 2022).

Similar instruments and detection limits are generally comparable to emissions from anthropogenic sectors, like O&G and coal mines in this study or landfills, agriculture, and waste management in previous studies (Maasakkers et al., 2023; Sadavarte et al., 2021; T. et al., 2022). However, no conclusive evidence shows by far that short-term (e.g., daily) satellite-based measurements with such detection limits can capture methane hotspots driven by natural sources (e.g., wetlands). In contrast, long-term (e.g., year-round) satellite-based measurements with much higher detection limits have shown the potential (Pandey et al., 2021).

Added/rewritten part in Title: Toward a versatile spaceborne architecture for immediate monitoring of the global methane pledge.

Added/rewritten part in Sect. 2.3: The transformation from visual inspection to automatic recognition would significantly advance long-term, global methane monitoring. However, no satisfactory set of criteria is found that could be suitable for this study. This is mainly because, in localized regions, methane budgets respond to the changes in not only super-emitters but also complex external factors (e.g., meteorology, topography, and background concentrations). Similar compromises are also adopted in previous studies. Therefore, automatic recognition enabled by artificial intelligence would play an essential role in the versatile spaceborne architecture for long-term, global methane monitoring (Ouerghi et al., 2021; Paoletti et al., 2018; Yang et al., 2018; Yu et al., 2017; Zhang et al., 2018).

Added/rewritten part in Sect. 2.5: The detection limit of this framework depends mainly on the TROPOMI-based and PRISMA-based methane retrievals, which have been well discussed in previous studies (Guanter et al., 2021; Hu et al., 2018). Here we have thus supplemented associated discussions on this detection limit briefly. As the robust relationship between the "minimum source" and the related methane enhancement interpreted by Jacob et al. (2016) and Guanter et al. (2021), the detection threshold for the TROPOMI instrument is 4000 kg/h with a wind speed of 5 km/h. Following the same relationship in the PRISMA instrument, we estimate that a retrieval precision of 114 ppb (6.1% with the assumed background concentration of 1850 ppb), such as in the case of the Hassi Messaoud site (Fig. S10e1), would lead to a detection limit of 800 kg/h for the same wind speed (analogous to the reported range of 500 ~ 900 kg/h) (Guanter et al., 2021; Irakulis-Loitxate et al., 2022). Similar instruments and detection limits are generally comparable to emissions from anthropogenic sectors, like O&G and coal mines in this study or landfills, agriculture, and waste management in previous studies (Maasakkers et al., 2023; Sadavarte et al., 2021; T. et al., 2022). However, no conclusive evidence shows by far that short-term (e.g., daily) satellite-based measurements with such detection limits can capture methane hotspots driven by natural sources (e.g., wetlands). In contrast, long-term (e.g., year-round) satellite-based measurements with much higher detection limits have shown the potential (Pandey et al., 2021).

Technical Points:

The title and the abstract are a bit perplexing. The multi-tiered reads mostly two-tiered. I think clarifying these basic points would be helpful for the reader. In the abstract, it would be nice if the authors could briefly describe what this “versatile spaceborne architecture" is, and what data it is based on using what methods. At the moment, one needs to read the paper to a large extent to get some idea of “this framework”. The paper could also benefit from adjusting the scope of the text to the results presented here.

Response: Thanks for this constructive suggestion. Accordingly, we have revised the title and abstract to clarify these key points, particularly distinguishing the two-tiered and versatile spaceborne architectures, and have also adjusted the scope of the text to the results presented here.

Added/rewritten part in Title: Toward a versatile spaceborne architecture for immediate monitoring of the global methane pledge

Added/rewritten part in Abstract: The global methane pledge paves a fresh, critical way toward Carbon Neutrality. However, it remains largely invisible and highly controversial due to the fact that planet-scale and plant-level methane retrievals have rarely been coordinated. This has never been more essential within a narrow window to reach the Paris target. Here we present a two-tiered spaceborne architecture to address this issue. Using this framework, we patrol the world, like the United States, China, the Middle East, and North Africa, and simultaneously uncover methane-abundant regions and plumes. These include new super-emitters, potential leakages, and unprecedented multiple plumes in a single source. More importantly, this framework is shown to challenge official emission reports that possibly mislead estimates from global, regional, to site scales, particularly by missing super-emitters. Our results show that, in principle, we can extend the above framework to be multi-tiered by adding upcoming stereoscopic measurements and suitable artificial intelligence, thus versatile for immediate and future monitoring of the global methane pledge.

Line 51: Ocko et al., 2021 only refers to the anthropogenic methane sources. It is important to state this precisely, not to confuse it with the large portion of methane emissions from natural sources. The current text might be misleading.

Response: Sorry for the misleading we caused. We have revised this sentence to make rigorous statements. Fortunately, methane is short-lived (~ ten years), and, particularly, that from human activities can be reduced in half using existing technologies by 2030 (Ocko et al., 2021).

Added/rewritten part in Sect. 1: Fortunately, methane is short-lived (~ ten years) (J et al., 2013), and, particularly, that from human activities can be reduced in half using existing technologies by 2030 (Ocko et al., 2021).

Line 55, line 59, and many other places: please check references.

Response: Thanks. We have carefully gone through the paper to check the references.

Fig. 1 How is "colocation" defined? Using what kind of criteria?

Response: Thanks. We have supplemented the definition the co-location criteria between the TROPOMI and PRISMA datasets. Regarding the identified regional hotspots, we also apply visual inspection to search for plumes within their surrounding 30 km scales (i.e., corresponding to the swath width of PRISMA) in the second tier of our framework (Irakulis-Loitxate et al., 2021; Martin et al., 2018; T. et al., 2022; Varon et al., 2020).

Added/rewritten part in Sect. 2.3: Regarding the identified regional hotspots, we also apply visual inspection to search for plumes within their surrounding 30 km scales (i.e., corresponding to the swath width of PRISMA) in the second tier of our framework (Irakulis-Loitxate et al., 2021; Martin et al., 2018; T. et al., 2022; Varon et al., 2020).

Fig. 2 What temporal periods are considered here to calculate the percentage?

Response: Thanks. We have supplemented the description of the temporal periods that are considered to calculate the percentages. The overpass moments are explicitly shown Fig. 1, most of which are inconsistent between for the first- and second-tier monitoring.

Added/rewritten part in Sect. 3.2: The overpass moments are explicitly shown Fig. 1, most of which are inconsistent between for the first- and second-tier monitoring.

Fig. 4 How to reconcile PRISMA and TROPOMI results? It seems there are still differences in the order of magnitude.

Response: Thanks. Yes, there are differences in the order of magnitude between the TROPOMI-based and PRISMA-based results, and we have supplemented additional discussions to clarify this issue. The main cause is that the TROPOMI-based and PRIMSA-based results represent the methane emissions from different special scales. The former results represent region-scale methane budgets, while the latter ones resolve the emission magnitude from the individual methane super-emitter therein (Fig. 1). Although the latter results can explain a large fraction of the former ones (Fig. 2), the gaps remain mainly due to inconsistent overpass moments between the two-tiered results or sources still missed by the PRIMSA-based results. In other words, closing the temporal gaps between the two tiers or improving the detection ability of the second tier would help to reconcile the first- and second-tiered results.

Added/rewritten part in Sect. 3.2: Note that there are differences in the order of magnitude between the TROPOMI-based and PRISMA-based results. The main cause is that the TROPOMI-based and PRIMSA-based results represent the methane emissions from different special scales. The former results represent region-scale methane budgets, while the latter ones resolve the emission magnitude from the individual methane super-emitter therein (Fig. 1). Although the latter results can explain a large fraction of the former ones (Fig. 2), the gaps remain mainly due to inconsistent overpass moments between the two-tiered results or sources still missed by the PRIMSA-based results. In other words, closing the temporal gaps between the two tiers or improving the detection ability of the second tier would help to reconcile the first- and second-tiered results.

Reply to comments on "Toward a versatile spaceborne architecture for immediate monitoring of the global methane pledge" by Yuchen Wang et al.

Reply to CC #1:

The article shows a very interesting approach to investigate the different methane emissions using available satellites (TROPOMI and PRIMA) and suggesting that a multitiered constellation could be implemented. Some comments on the article of possible improvements.

Response: We truly appreciate your positive responses and valuable comments. We have addressed all of them in our revised manuscript.

The followings are our point-to-point responses to the reviewer's comments. The responses are shown in brown font, while the added/rewritten parts are presented in blue font. All revised figures and tables are also included in the manuscripts.

Line 60 you introduce the term "super-emitters" for first time, the term should be defined better (how big/small, released methane, how spread, etc.) in contrast with hot spots and area sources. This should be tailored for the satellite swath and resolution.

Response: Thanks for this valuable comment. We have supplemented the descriptions to clarify the definition of "super-emitters". In this study, super-emitters can generally be defined to be emission sources that comprise highly concentrated methane plumes and dominate localized methane budgets (~ 5×5 km^2). In contrast to region-scale hotspots (or area sources), they can be attributed to individual facilities (e.g., factories, chimneys, and pipelines), typically with side lengths varying from several meters to tens of meters depending on monitoring instruments.

Added/rewritten part in Sect. 1: Super-emitters can generally be defined to be emission sources that comprise highly concentrated methane plumes and dominate localized methane budgets (~ 5×5 km^2). In contrast to region-scale hotspots (or area sources), they can be attributed to individual facilities (e.g., factories, chimneys, and pipelines), typically with side lengths varying from several meters to tens of meters depending on monitoring instruments.

Between lines 80 to 92 a review of existing and capable of detecting methane satellites is shown. However, the swath, passes, resolution, etc. is not given for all satellites. I would suggest to add a table with such information. This would help to better understand/propose a future multi-tiered constellation which could act globally.

Response: Thanks. This is a very valuable suggestion. We have supplemented a table (Table 1) to collect the potential satellites and their necessary information (e.g., swath and resolution).

A conclusions section with a better explanation of what number of satellites (which ones in the pipeline / resolution), and aircrafts needed to have a proper coverage would be needed. Also, would it be night monitoring important, which method or missions could be used? Atmospheric Lidars? Would the retrieval of structured atmospheric column help the analysis?

Response: Very illuminating suggestions. We have supplemented brief discussions to clarify these three issues. Overall, this multi-tiered framework based on multifarious satellites, aircrafts, and UAVs keeps pursuing wider coverages and faster revisits. We would thus derive the next objective in this manner, i.e., how to achieve effective, efficient, and economic monitoring of global methane pledges, in which how to make better coverage-resolution balance between instruments is crucial. This will be the topic of a next separate study.

Second, yes, nighttime methane monitoring is important because abnormal leakages or pulses might also occur during nighttime (Plant et al., 2022; Poindexter et al., 2016). In these events, the LIDAR-equipped ones (involving satellites, e.g., MERLIN) can allow to retrieve methane fluxes at all-latitudes, all-seasons, and all-weather (involving nighttime) as they are not relying on sunlight. Fourth, better characterizing methane vertical profile would in principle help to optimize our analysis, like minimizing the uncertainties in tropospheric air mass factors and subsequent methane enhancements.

Added/rewritten part in Sect. 3.4: Note that such a multi-tiered framework based on multifarious satellites, aircrafts, and UAVs keeps pursuing wider coverages and faster revisits. We would thus derive the next objective in this manner, i.e., how to achieve effective, efficient, and economic monitoring of global methane pledges, in which how to make better coverage-resolution balance between instruments is crucial. This will be the topic of the next separate study.

Third, nighttime methane monitoring is important because abnormal leakages or pulses might also occur during nighttime (Plant et al., 2022; Poindexter et al., 2016). In these events, the LIDAR-equipped ones (involving satellites, e.g., MERLIN) can allow to retrieve methane fluxes at all-latitudes, all-seasons, and all-weather (involving nighttime) as they are not relying on sunlight. Fourth, better characterizing methane vertical profile would help to optimize our analysis, like minimizing the uncertainties in tropospheric air mass factors and subsequent methane enhancements.

Cosmetics:

Spacing between text and references. In Line 57, 59, 136, 223, 225, 244, 312, 343, 360.

Response: Thanks. We have supplemented these necessary blank spaces.

Reference in line 117, is this correct format for the current article? In contract to the one in line 145. Is it need to have same info twice?

Response: Thanks. We have checked the format of the reference. Besides, in Line 117 and Line 145, we have deleted the repetitive references.

Reference

Plant, G., Kort, E. A., Brandt, A. R., Chen, Y., Fordice, G., Gorchov Negron, A. M., Schwietzke, S., Smith, M. and Zavala-Araiza, D.: Inefficient and unlit natural gas flares both emit large quantities of methane, Science (80-.)., 377(6614), 1566–1571, doi:10.1126/science.abq0385, 2022.

Poindexter, C. M., Baldocchi, D. D., Matthes, J. H., Knox, S. H. and Variano, E. A.: The contribution of an overlooked transport process to a wetland's methane emissions, Geophys. Res. Lett., 43(12), 6276–6284, doi:https://doi.org/10.1002/2016GL068782, 2016.