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.