Reply to Referee #1

The article presents a way to optimize the design of a reference network within an area of interest (in this case for Methane remote sensing stations in Africa, but it can be applied to other species and regions), based on the reduction of emission uncertainties using a Bayesian inversion framework.

It is important to note that the determination of the optimal number and spatial configuration of the network starts from a predetermined pool of candidate measurement sites, where sufficient expertise and support is deemed to be available.

The paper is clearly written, the methodology is sound, and while the individual optimal network configuration results are dependent on the choice of various key parameters, the robustness analysis clearly identifies a significant group of stations that are selected under almost all conditions.

Response:

We sincerely thank the referee for the positive and constructive comments on our manuscript. Below, we offer detailed responses addressing each point raised.

General remarks:

1. line 289 and 290 on cloud statistics: Are only day-time hours considered?

Response: Yes. Only daytime hours are considered because the default instrument assumed in this study is the EM27/SUN spectrometer, which relies on direct solar radiation and therefore operates during daytime. We have clarified this in Lines 304-308.

Lines 304-308: Daily cloud conditions are derived from hourly cloud-fraction data between 08:00 and 18:00 local time, corresponding to the typical daytime observation window of the EM27/SUN spectrometer (Frey et al., 2019). Under the default settings, a day is classified as cloud-contaminated and excluded if more than 10% of the hourly records (maximum cloudy-hour fraction, MF) have a cloud fraction (CF) greater than 0.5.

2. Section 3.4: A curious omission when it comes to quantifying the impact of certain variables, is the footprint sensitivity. This parameter is currently calculated based on the latter half of each month and thus comprises of 16 to 30 day backward integration lengths. Would it be possible to evaluate a subset of short vs long integration times?

Response: We evaluated the sensitivity of the network design to footprint backward-integration length by repeating the optimization with fixed 10-, 15-, 20-, and 25-day windows. The optimal network size varies across these tests because shorter integration periods reduce long-range transport sensitivity and spatial coverage, thereby requiring denser station deployment to achieve comparable marginal uncertainty reduction. Specifically, the recommended number of additional sites increases from only 11 for the 25-day window to 21 for the 10-day window. Despite this variation in network size, the same ten high-priority sites are retained in every optimal configuration, indicating that the principal spatial priorities are robust to the assumed footprint integration length. The new sensitivity results have been added to Table S4 and discussed in Lines 479-481.

Lines 479-481: Footprint integration length shows a similar effect: as the window decreases from 25 (Int25) to 10 (Int10) days, the optimal network size increases from 11 to 21 sites, reflecting the need for denser spatial sampling when long-range sensitivity is reduced.

Table S4. The sensitivity tests on parameters.

Parameters		Test Name	Test Value	**Optimal Site Number** (10)	**Optimal Site Configuration** [Arta, Bujumbura, DaresSalam, Kalene, Kigali, Kimberley, Maun, Nile, Tamanrasset, Wits]
Observation uncertainty (ppb) (5)		R1	1	10	- [Arta, Bujumbura, DaresSalam, Kalene, Kigali, Kimberley, Maun, Nile, Tamanrasset, Wit]
		R10	10	10	- [Arta, Bujumbura, DaresSalam, Kalene, Kigali, Kimberley, Maun, Nile, Tamanrasset, Wit]
		R100	100	12	- [Arta, Bujumbura, Dahra, DaresSalam, Kalene, Kigali, Kimberley, Maun, Niakhar, Nile, Tamanrasset, Wits]
		R1000	1000	21	- All candidates
Cloud effect	Cloud fraction (0.5)	CF0.3	0.3	19	- [Arta, Assosa, Bangui, Bujumbura, Dahra, Dangbo, DaresSalam, Dja-Somalomo, Kalene, Kigali, Kimberley, Lope, Maun, Ndjamena, Niakhar, Nile, Ntui, Tamanrasset, Wits]
		CF0.4	0.4	13	- [Arta, Bangui, Bujumbura, Dahra, Dangbo, Kalene, Kigali, Kimberley, Maun, Niakhar, Nile, Tamanrasset, Wits]
		CF0.6	0.6	2	- [DaresSalam, Nile]
		CF0.7	0.7	2	- [Arta, DaresSalam]
	Maximum cloudy-hour fraction (0.1)	MF0	0	13	- [Arta, Assosa, Bujumbura, Dahra, Dja-Somalomo, Kalene, Kigali, Kimberley, Maun, Niakhar, Nile, Ntui, Wits]
		MF0.2	0.2	4	- [DaresSalam, Kalene, Maun, Nile]
		MF0.3	0.3	1	- [DaresSalam]
		MF0.4	0.4	1	- [DaresSalam]
System Parameter	ε (0.6%)	ε_0.5%	0.5%	14	- [Arta, Bujumbura, Dahra, DaresSalam, Dja-Somalomo, Kalene, Kigali, Kimberley, Lope, Maun, Niakhar, Nile, Tamanrasset, Wits]
		ε_0.7%	0.7%	7	- [Bujumbura, DaresSalam, Kalene, Kimberley, Maun, Nile, Wits]
	Integration days (Full: 31 in Jan. and Jul.)	Int10	10	21	- All candidates
		Int15	15	18	- [Arta, Bangui, Bujumbura, Dahra, Dangbo, DaresSalam, Djougou, Gondar, Kalene, Kigali, Kimberley, Maun, Ndjamena, Niakhar, Nile, Ntui, Tamanrasset, Wits]
		Int20	20	14	- [Arta, Bujumbura, Dahra, Dangbo, DaresSalam, Djougou, Kalene, Kigali, Kimberley, Maun, Niakhar, Nile, Tamanrasset, Wits]
		Int25	25	11	- [Arta, Bujumbura, Dahra, DaresSalam, Kalene, Kimberley, Maun, Niakhar, Nile, Tamanrasset, Wits]

3. line 465: Here you discuss a test where you vary the prescribed network size from 1 to 21 additional sites. However, all these simulations start from the presumption that all candidate sites in each variation will be selected at the same time. Another scenario would be an organic growth scenario, where stations are selected and added to the network, one at a time, each one aiming to maximize the uncertainty reduction. Would such a network configuration differ with the first approach?

Response: We have added a sequential network-growth test to represent incremental deployment. Starting from the base network (9 operational and 4 planned sites), candidate stations are introduced one at a time, with each addition chosen to provide the largest marginal reduction in posterior uncertainty given the stations already selected. This produces a nested sequence of network configurations rather than independently optimized configurations at each prescribed network size. The first ten stations selected through this procedure are identical to those in the independently derived ten-site solution and appear in the same order, indicating that the inferred deployment priorities are not sensitive to whether the network is planned simultaneously or expanded sequentially. The new analysis is presented in Fig. S12 and discussed in Lines 491-495.

Lines 491-495: A complementary sequential-growth experiment, in which one site is added at each step to maximize the additional uncertainty reduction conditional on the previously selected network, identifies the same ten sites in the same order (Fig. S12). This agreement further demonstrates the robustness of the site ranking across alternative deployment strategies. The framework can therefore support a practical, prioritized rollout when the number of new stations is constrained by budget or logistics.

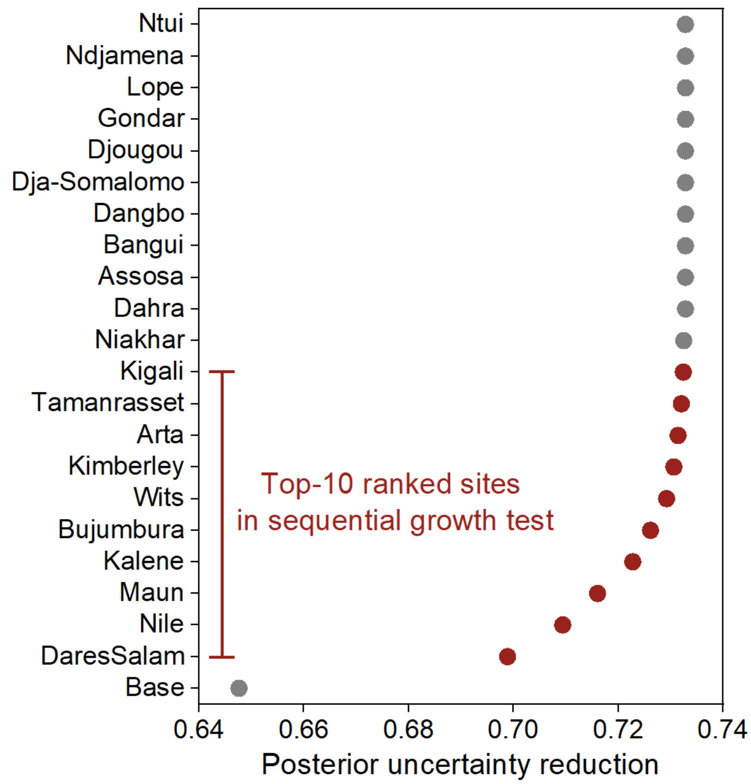

Figure S12. Sequential network growth and uncertainty reduction for July. Posterior uncertainty reduction for the base network and for each nested network obtained by adding one candidate site at a time. At each step, the site providing the largest additional reduction in posterior uncertainty, conditional on all previously selected sites, is added to the network. Red symbols indicate the first 10 sites selected along the sequential growth pathway, while grey symbols denote the remaining lower-ranked additions. The flattening of the curve indicates diminishing information gain as the network expands.

Minor remark:

4. line 48: "particularly given the region's high vulnerability to climate change" seems like a weird fit in this sentence? Shouldn't it be the end of the follow up sentence? The potential for rapid…further elevates the region's importance in the global CH4 budget, particularly given the region's high vulnerability to climate change. Or even the one after that. Despite this growing significance and the region's high vulnerability to climate change, African…

Response: We have modified the statement here to strengthen the logic, as shown in Lines 52-54.

Lines 52-54: Despite this growing significance, African methane emissions remain among the most uncertain of all major source regions, underscoring the need for improved constraints given the region's high vulnerability to climate change (Saunois et al., 2025; Gunaratne et al., 2025).

Question:

5. As stated by the authors, the methodology can be applied to other species, and since the geographical distribution of emission sources differ between different species, so will the resulting optimal network configurations. In practice however, networks are rarely targeted towards a single molecule. What adjustments need to be made for the method to work on a set of molecules?

Response: We have added a discussion of how the framework could be generalized to multi-species networks. In such an application, each species would require its own prior flux error covariance, transport sensitivity, and observation-error representation. Because uncertainty reductions are not directly comparable across species, they could be normalized and combined using a weighted objective function, or alternatively treated through a multi-objective optimization that explicitly represents trade-offs among species. Practical constraints such as instrument compatibility and shared site infrastructure would also need to be included. This discussion has been added to the Lines 562-568 in the Discussion.

Lines 562-568: For multi-species networks, species-specific uncertainty reductions could be normalized and combined within a weighted objective function, with the weights reflecting scientific or policy priorities. Alternatively, a multi-objective formulation could be used to identify configurations that balance trade-offs among species. Practical implementation would also need to account for instrument compatibility and shared infrastructure. For example, the EM27/SUN instrument adopted as the default platform in this study can simultaneously provide column observations of CH_4, CO_2, and CO, enabling the same observational site to contribute to the optimization of multiple species.