Review of Schooling et al.: Potential of point source imaging satellite instruments to infer diffuse methane emissions: a theoretical case study of the Near-Infrared Multispectral Camera (NIMCAM)

General Comments:

This manuscript presents a closed-loop observing system simulation experiment (OSSE) to evaluate the capability of a high-resolution multispectral imager (NIMCAM) to constrain diffuse methane emissions over tropical Africa under cloud- and aerosol-limited conditions. The study is well-motivated, the methodology is clearly described, and the results are internally consistent. The work addresses an important limitation of current global satellite observing systems: the loss of clear-sky data in persistently cloudy regions.

The results demonstrate that increased spatial resolution can substantially improve clear-sky sampling and, under the assumptions of the OSSE, lead to improved uncertainty reduction in methane flux inversions. This is especially true in regions where lower-resolution instruments provide few to no valid observations, highlighting a robust advantage of the NIMCAM configuration in persistently cloud-covered regions.

However, some key assumptions regarding retrieval error structure, sampling behavior, and transport modeling are not fully characterized within this manuscript. These assumptions are central to the magnitude of the performance gains and may lead to a somewhat optimistic estimate of capability. Some clarification would strengthen the robustness and interpretability of the conclusions.

Specific Comments:

1: Error scaling and sampling

The NIMCAM spectral configuration (three ~1 nm channels near 1.64 μm), together with the described use of adjacent bands to characterize methane absorption, water absorption, and surface reflectance, appears consistent with a differential or matched-filter retrieval. Such methods can introduce spatially correlated and scene-dependent errors driven by surface reflectance, aerosols, and viewing geometry.

If such correlations are present, the effective sample size is reduced ($N_{\text{eff}} \ll N$), and the expected error reduction with increasing sampling density is weaker than $1/\sqrt{N}$. This effect may be particularly relevant for diffuse emission signals, where low signal-to-noise ratios and broad spatial structure increase sensitivity to any correlated retrieval errors.

The authors define super-observation error as:

$$\delta = \delta_l + \frac{\delta_{\text{GOSAT}}}{\sqrt{N}}$$

Where δ_l is a lower bound (constant term) and $\delta_{\mathrm{GOSAT}}/\sqrt{N}$ is the random noise reduction. They state that δ_l represents sub-grid variability and scene-dependent effects.

This appropriately prevents unrealistically small errors as the number of observations increases. However, this term does not explicitly represent reduced effective sample size, spatial correlation, or scene-dependent retrieval errors. As a result, the relationship between sampling density and information content may be sensitive to these assumptions.

The relative improvement of NIMCAM over TROPOMI is evaluated within a consistent OSSE framework that appropriately treats both instruments under the same transport and inversion assumptions. The relative comparison is expected to be robust provided that the underlying error structures are comparable.

However, the NIMCAM measurement approach, based on a small number of narrow spectral channels, may lead to retrieval errors that differ in structure from those of TROPOMI, particularly with respect to spatial correlation and scene dependence. If present, such differences would affect the effective number of independent observations and the scaling of uncertainty with sampling density. As a result, the relative performance gains may be moderately sensitive to assumptions about error independence that do not affect both instruments equally.

The retrieval formulation is not explicitly described. The manuscript does not explicitly define the forward model used to relate measured radiances to methane column enhancements, nor does it characterize the resulting error structure beyond a prescribed per-pixel random error (Section 2.6). The manuscript references Woodwark et al. (2026) for these details, but this information is not included here and Woodwark et al. (2026) is not publicly available at the time of this review (to the best of my knowledge). I understand that Woodwark et al. (2026) may be published before this work. Providing a pre-print during review would help support assessment of these assumptions.

A concise description of the retrieval approach and its expected error characteristics would make the analysis more self-contained and help assess the robustness of the sampling-based performance gains.

2: Transport error assumptions

The OSSE uses GEOS-Chem for both the generation of synthetic observations and the inversion (Section 2.6), with differences only in the emissions field. This configuration avoids inconsistencies between forward and inverse modeling but also excludes structural transport error. It is commonly referred to as an “identical twin” OSSE.

In practice, transport uncertainty is a significant component of inversion error and introduces spatially coherent model-data mismatch. While this limitation applies to both NIMCAM and TROPOMI, its impact may not be fully symmetric. The primary advantage of NIMCAM in this study arises from increased sampling density and more spatially distributed observations under cloud and aerosol filtering. In the presence of transport error, additional observations may lead to spatially correlated residuals, which are not explicitly represented in the current error model.

The manuscript does note the importance of transport error (Section 3.4), but it is not explored within the current framework. A complementary fraternal twin OSSE would help quantify sensitivity to transport assumptions, although this may be beyond the scope of the current study.

Technical Corrections:

This is a very well-written manuscript. I noted only a few minor spelling and grammatical issues:

Spelling errors

Section 2.2
"capabclity" → should be *capability*
"satellities" → should be *satellites*

Section 2.4
"probalistic" → should be *probabilistic*

Minor grammatical / wording issues

Section 1
"taking advantage sensitivity" → should be *taking advantage of the sensitivity*

Section 2.1
"spectral various" → should be *spectral variations*

Section 3.2
"are are primarily influenced" → duplicated word

Section 3.4
"values corresponding to prior knowledge" → slightly awkward phrasing; could be *prior estimates*
"posterior estimate is much closer to the observations" → should likely be *closer to the truth*