

Author response to Referee #2 (RC2)

Radiative Constraints on VIIRS Nighttime Detectability of Lower-Tropospheric Methane
(egusphere-2026-4225)

We thank Referee #2 for the constructive review and the encouraging assessment. Each comment is addressed below.

General comments

General comment

This is an interesting paper exploring the feasibility of methane detection using the VIIRS satellite's MWIR band. Overall, the technical approach is sound and conclusions are generally well-evidenced. My main comments concern clarity, I did have some confusion reading the 'spatial averaging' section. I also think that the discussion of the location and strength of methane absorption lines is underdeveloped and could use an additional figure (e.g. pulling HITRAN and showing the lines within the spectral response of that particular VIIRS channel). This also would inform some of the saturation discussion. I identify the main weakness of the paper is a lack of observational validation. The data to do so readily exists, but I understand the argument that such analysis is outside the theoretical scope of the paper. Still, I think at least pulling an image to show what the MWIR channel looks like, maybe finding an example of a 'super emitter' case would help ground the reader. But overall, the conclusions are well written and would be quite interesting to those developing the next generation of overhead sensors for gas detection. Great work!

Author response: We thank the referee. The three main requests are addressed as follows: (1) a HITRAN-based figure of the methane absorption within the M12 spectral response (new Fig. 1); (2) clarification of the spatial averaging section (Eq. 5 limitations, plume dilution, and treatment of the emissivity term); and (3) observational grounding through a VIIRS M12 image over the study site (new Fig. 2) and a real-world extreme-release example (Aliso Canyon). The new Fig. 1 also supports the saturation discussion, because it shows that M12 sits on a weak wing of the methane feature. We agree that observational validation is the main remaining weakness. Because this study is a theoretical radiative sensitivity analysis, validation against satellite observations of real plumes is outside its scope, and we now state explicitly in the Discussion (L. 375-384) that the simulations are not observationally validated. We have added a figure (Fig. 8) that makes clear how far the results are from detection.

Changes in the manuscript:

- **Figs. 1, 2, 8:** New figures (see below).
- **L. 378-384:** Limitations paragraph states the lack of observational validation.

Specific comments

Specific comment 1

More detail is needed on the absorption/emission spectra in the MWIR. The specific structure

is referenced throughout “... VIIRS M12 band, which has a small overlap with the wing of methane’s MWIR absorption feature”. Pulling HITRAN and plotting spectral absorption along with the spectral response of the instrument would be a helpful thing to refer back to throughout the paper. Also, there is more than one MWIR band in VIIRS and I’m assuming M12 (3.61-3.79 μ m) is the one that spans the strongest absorption feature but that needs to be shown explicitly? After all, there is a channel that spans very close to that range that is much higher resolution (I4: 3.55-3.93 μ m – 375m resolution versus 750m for M12). Also, I didn’t see a mention of M12’s spectral range (just a note its centered around 3.7 μ m) – that needs to be in there somewhere, preferably via plotting the spectral response.

Author response: We thank the referee. We added the M12 spectral range (3.61 to 3.79 μ m) to the Introduction and added a new Figure 1 with HITRAN2024 methane absorption plotted against the NOAA-21 M12 relative spectral response. Panel (a) spans 3.0 to 4.0 μ m and shows that M12 does not span the strongest absorption feature; it overlaps only the weak long-wavelength wing of the 3.3 μ m band, where the response-weighted mean normalized absorbance is about 0.1% of the maximum. This is the premise of the hypothesis tested. Panel (b) shows the line-by-line cross-section from 3.5 to 3.9 μ m. On I4: we selected M12 because it has lower noise on NOAA-21; at a typical scene temperature of 270 K the NEdT is 0.158 K for M12 and 0.416 K for I4 (Wang et al., 2024), which outweighs the finer 375 m resolution for a detection-limited problem. The statement is now in Sect. 1.5.

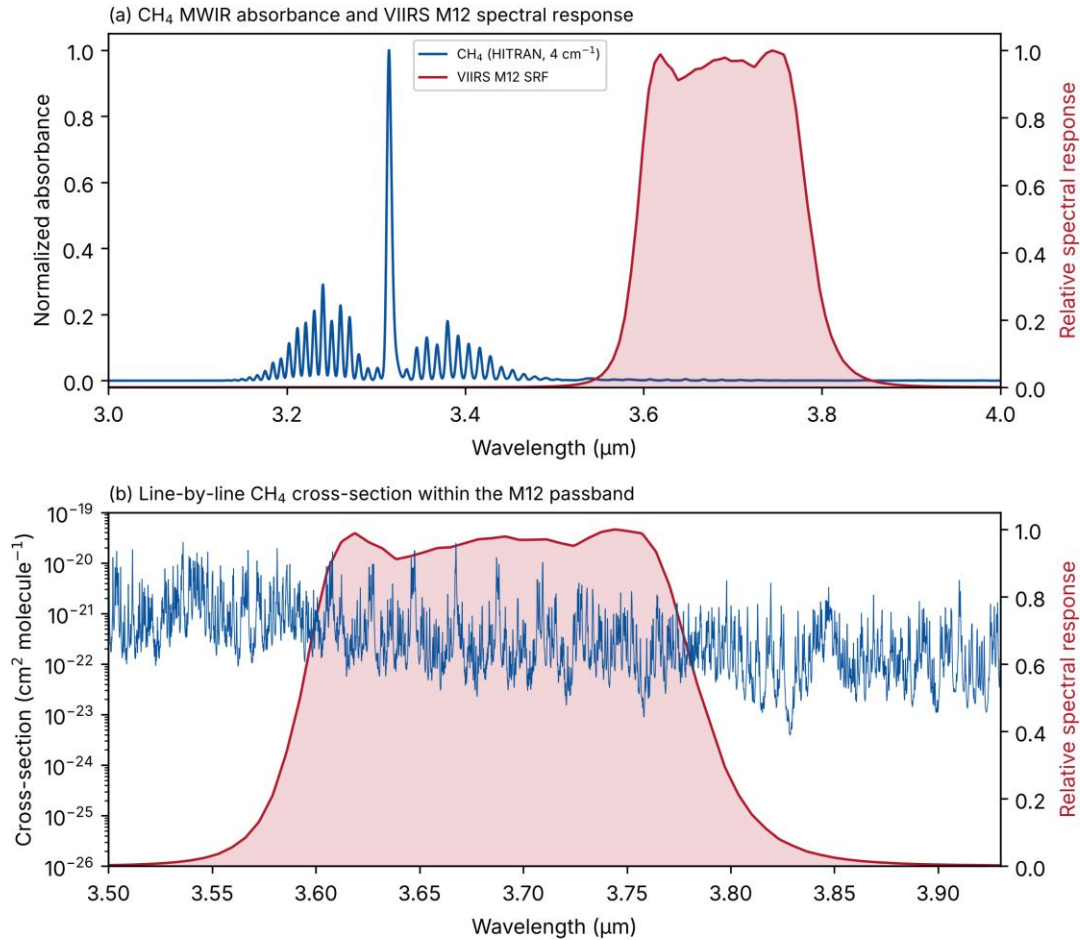


Figure 1. (a) Normalized methane absorbance from 3.0 to 4.0 μm , computed from HITRAN2024 line parameters (Gordon et al., 2026) at 296 K and 1 atm, optically thin limit, smoothed with a 4 cm^{-1} Gaussian and normalized to its maximum near 3.3 μm . The red curve is the VIIRS M12 relative spectral response. (b) Line-by-line methane absorption cross-section from 3.5 to 3.9 μm under the same conditions, with the M12 response. The M12 band (3.61 to 3.79 μm) lies on the long-wavelength wing of the methane MWIR feature, where its response-weighted mean normalized absorbance in (a) is about 0.1% of the maximum.

Changes in the manuscript:

- **L. 60:** "VIIRS M12 (3.61-3.79 μm) band".
- **L. 77-86:** Figure 1 callout (L. 78), figure and caption (L. 80-86).
- **L. 211-213:** I4 rationale with NEdT values and citation.
- **Reference list:** Gordon et al. (2026), JQSRT, 353, 109807, <https://doi.org/10.1016/j.jqsrt.2026.109807>; Wang, Cao, and Blonski (2024), IEEE TGRS, 62, 5006313, <https://doi.org/10.1109/TGRS.2024.3458869>.

Specific comment 2

Overall, I'm not totally following the spatial averaging discussion. It makes sense that you'd

give up some spatial resolution in order to improve your NETD and therefore have a lower detection threshold, but is just diving by the square root of the number of pixels valid? I'd show a reference or a derivation. Do you get an enhancement in all kinds of sensor noise? (shot noise, read noise, fixed pattern noise, thermal noise, etc).

Author response: We thank the referee. Division by the square root of N is the standard error of the mean and is valid for N independent measurements with equal random noise (Bevington and Robinson, 2003). It therefore applies to random instrument noise such as uncorrelated shot, read, and thermal noise. It does not apply to fixed-pattern noise, calibration uncertainty, correlated noise, or scene-dependent surface-emissivity variability, none of which need decrease at this rate. We now state this where Eq. (5) is introduced. We also added that the 750 m footprint is already large relative to a typical point-source plume, so averaging adjacent pixels dilutes the plume signal unless the plume fills the averaged footprint. Finally, the CAMEL-derived term of 0.185 K is a proxy for scene-scale emissivity heterogeneity and is not assumed to average down, because the spatial covariance at the M12 scale and the scale mismatch between CAMEL (about 5 km) and M12 (750 m) are not resolved here.

Changes in the manuscript:

- **L. 306-312:** Eq. (5), citation, and limitation to random instrument noise.
- **L. 330-331:** Dilution of the plume signal.
- **L. 343-345, 347-349:** Emissivity term not assumed to decrease with averaging; scale mismatch stated.
- **L. 368-373:** Table 4 caption updated.

Specific comment 3

An overall weakness of the study is a lack of observational grounding. I get that it's a theoretical paper, and so a real data processing effort would be out of scope but I think even showing an image of VIIRS in the MWIR over HUBC would be helpful to ground things.

Author response: We agree and added a new Figure 2 showing the NOAA-21 VIIRS M12 brightness temperature for the 19 October 2023 nighttime overpass, with the study site marked. Panel (a) is a regional view and panel (b) an enlarged view with native 750 m pixels. The site pixel is 279.39 K. A full observational detection analysis is outside the scope of this theoretical study.

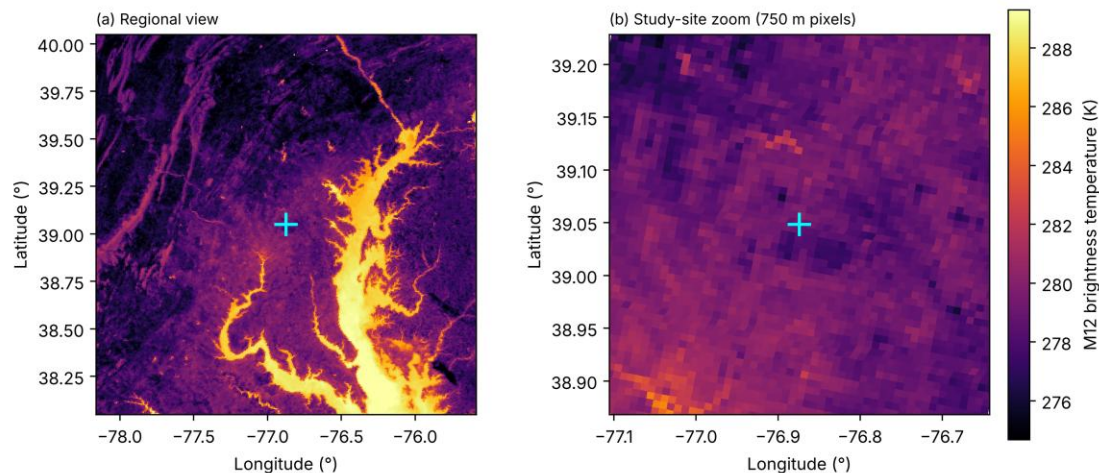


Figure 2. NOAA-21 VIIRS M12 brightness temperature for the nighttime overpass of 19 October 2023 (about 06:56 UTC) at a near-nadir view angle (4.9 deg). The cross marks the study site. (a) Regional view. (b) Enlarged view of the study site showing native 750 m pixels. Brightness temperatures were computed from the M12 sensor data record using the standard scale and offset, and the color scale spans the 1st to 99th percentile of the regional view.

Changes in the manuscript:

- **L. 106-107:** Figure 2 callout.
- **L. 111-116:** Figure 2 and caption.

Specific comment 4

Can you ground the ‘enhancement profiles’ in something real? Maybe find a real-world example of a super emitter event and say, maybe, what surface value that corresponded to? Just so the readers can gauge. 9x sounds like a lot to me, but has that ever happened/does it happen all the time?

Author response: We thank the referee. We added the 2015-2016 Aliso Canyon blowout as an observational example of an extreme release, with a peak emission of about 60 t CH₄ per hour and about 97 kt released over roughly four months (Conley et al., 2016), noting that it is an extreme case and not a global upper bound. On whether 9x occurs: we do not claim that a pixel-mean 9x enhancement is routine. The 2x to 9x cases are idealized radiative sensitivity scenarios, not emission-rate equivalents, because the mapping from emission rate to a pixel-mean vertical enhancement depends on wind, source height, mixing depth, turbulent diffusion, plume age, and fractional M12-pixel coverage and would require a coupled dispersion and radiative-transfer model. To help readers gauge magnitudes, Table 1 gives the resulting mixing ratios (for example 17.05 ppmv at the surface for 9x).

Changes in the manuscript:

- **L. 181-184:** High-enhancement scenarios described as idealized sensitivity cases; EPA definition as reference only.

- **L. 379-382:** Limitation on source-rate equivalence.
- **L. 391-396:** Aliso Canyon paragraph.
- **Reference list (~L. 1064):** Conley et al. (2016), Science, 351, 1317-1320.

Specific comment 5 (abstract)

I don't quite understand this sentence in the abstract "the detectable signal is therefore driven by the plume's thermal emission (path radiance) rather than surface absorption". Do you mean surface emission here? Also, I think of path radiance as being light scattered into/emitted by the path in between your target and your sensor. Here, your target is the gas plume so I'd think that phrase would be "the detectable signal is therefore driven by the plume's thermal emission rather than surface emission".

Author response: We agree; the wording was imprecise. "Path radiance" has been removed. The sentence now contrasts the plume's own thermal emission with absorption of surface-emitted radiation, which is the mechanism tested and not supported by our results.

Changes in the manuscript:

- **Abstract L. 12-14:** "...the detectable signal is therefore driven by the plume's own thermal emission rather than by absorption of surface-emitted radiation."

Technical corrections

Technical correction 1

I'd put a plot of SNR vs CH₄ scale factor somewhere, with a horizontal line at 1 to show just how far away we are from detection. Just a suggestion though, maybe plot it and see how it looks. A comment in the captions of Figure 4 and 5 restating the NETD goal you're trying to reach would also be welcome, to drive home the point that those plots are nowhere even close.

Author response: We thank the referee and added the plot as new Figure 8. It shows residual-layer SNR versus CH₄ scale factor (2x to 9x) for the instrument-only noise floor (NEdT = 0.158 K) and for the operational noise floor including surface-emissivity variability (sigma_combined = 0.193 K, 3x3 window). Lines show the CAMEL-matched emissivity (0.91) and shading spans emissivities 0.89 to 0.99. A dotted line marks SNR = 1 and a dashed line marks the SNR = 2 detection threshold. With the emissivity term included, no case reaches SNR = 2 (maximum 1.79). Regarding restating the NEdT goal in the captions of the NBL and RL figures (now Figures 5 and 6): the NEdT of 0.158 K and the SNR ≥ 2 criterion are stated in Sect. 1.5 (L. 206-212) and Sect. 2.2 (L. 250-252), and Figure 8 shows the distance to the detection goal directly, so those two figures are left unchanged.

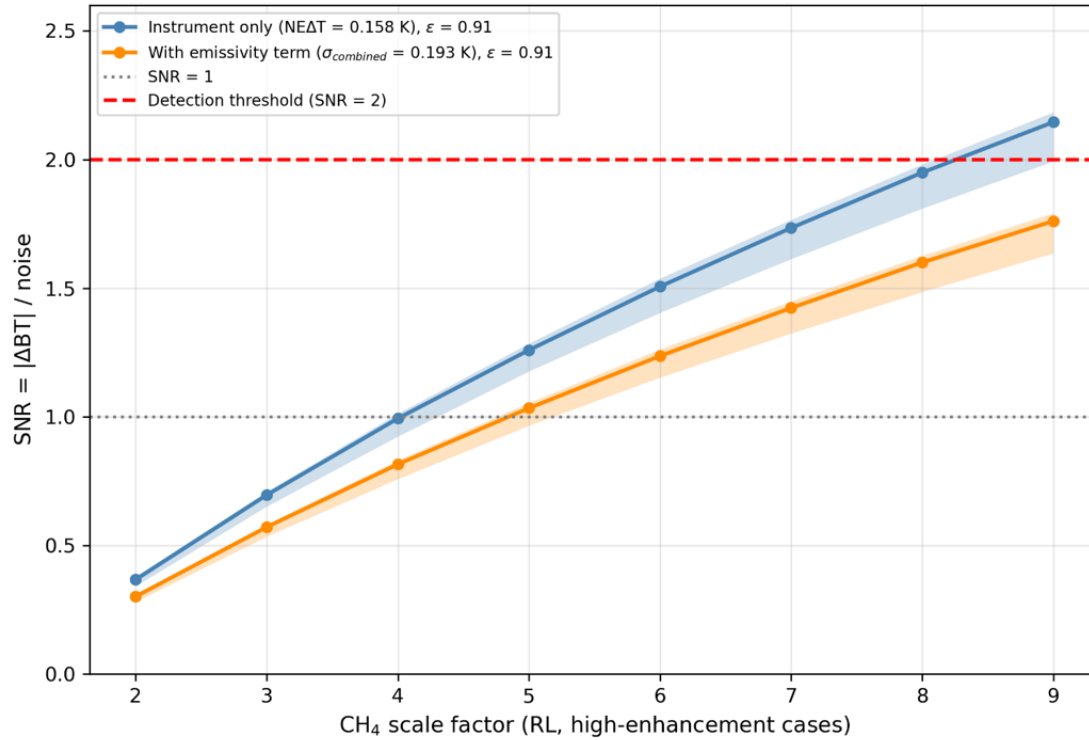


Figure 8. Residual-layer SNR versus CH₄ scale factor (2-9x) for the instrument-only noise floor ($NE\Delta T = 0.158$ K) and the operational noise floor including surface-emissivity variability ($\sigma_{combined} = 0.193$ K, 3x3 window). Lines show $\epsilon = 0.91$ (CAMEL-matched); shading spans $\epsilon = 0.89$ -0.99. The dotted line marks SNR = 1 and the dashed line marks the detection threshold (SNR = 2). With the emissivity term included, no case reaches SNR = 2.

Changes in the manuscript:

- **L. 350:** Figure 8 callout.
- **L. 351-355:** Figure 8 and caption.
- **L. 356-363:** Combined SNR reported: 1.76 at $\epsilon = 0.91$ (0.339 K); overall maximum 1.79 at $\epsilon = 0.89$ and 9x.

Technical correction 2

Cite MethaneSAT somewhere. Maybe where you talk about SWIR/daytime detection work.

Author response: MethaneSAT is now cited where SWIR and daytime methane retrievals are discussed.

Changes in the manuscript:

- **L. 33-34:** "...including from dedicated methane missions such as MethaneSAT (Chan Miller et al., 2024)."

- **Reference list (~L. 1054):** Chan Miller, C., et al.: Methane retrieval from MethaneAIR using the CO₂ proxy approach: a demonstration for the upcoming MethaneSAT mission, Atmos. Meas. Tech., 17, 5429-5454, <https://doi.org/10.5194/amt-17-5429-2024>, 2024.

Technical correction 3

Don't need to capitalize the three key variables on line 84

Author response: Corrected; the three variables are now lowercase.

Changes in the manuscript:

- **L. 96-98:** "(1) plume vertical extent; (2) methane concentration; and (3) surface properties".

Technical correction 4

What's an 'optically active gas plume'? As opposed to what? This could be a common term, I've just never heard of it.

Author response: We agree the term was unclear and replaced it with "methane gas plume".

Changes in the manuscript:

- **L. 40:** "...a methane gas plume creates a thermal contrast signal..."

Summary of new and revised figures

- **Fig. 1 (new, L. 80-86):** HITRAN2024 CH₄ absorbance and cross-section with the NOAA-21 M12 response.
- **Fig. 2 (new, L. 111-116):** NOAA-21 M12 brightness temperature scene over the study site.
- **Figs. 3, 4:** Renumbered; content unchanged.
- **Figs. 5, 6:** Retained; only "super-emitter" wording changed.
- **Fig. 7 (updated, L. 321-325):** 3x3 histogram with corrected brightness temperatures.
- **Fig. 8 (new, L. 351-355):** RL SNR versus CH₄ scale factor with SNR = 1 and 2 lines.
- **Figs. A2, A5:** Relabeled to "high-enhancement".