Understanding the Potential and Limitations of Sentinel 2 for Methane Mapping

Javier Gorroño[1], Daniel Varon[2,3], Elena Sanchez-García[1], Itziar Irakulis-Loitxate[1], Luis Guanter[1].

[1]Research Institute of Water and Environmental Engineering (IIAMA), Universitat Politècnica de València

[2]School of Engineering and Applied Science, Harvard University, Cambridge, 02138, USA, [3]GHGSat Inc., Montréal, H2W 1Y5, Canada

Correspondence: Javier Gorroño(jagorvie@upv.es)

Introduction

Recent research in Varon, 2021; Irakulis, 2021 and Ehret, 2021, has shown the potential of the Sentinel 2 (S2) mission to monitor methane point emissions from space.

Previous efforts, such as in Cusworth et al. 2019, have studied the capability of hyperspectral sensors to quantify methane plumes.

This work is directed towards the development of an end-to-end simulation that objectively shows the potential and limitations of the Sentinel 2 mission for methane mapping .

Simulation methodology

The transmittance of a methane plume can be directly convolved to the TOA radiance at the cost of an error...

$$L_{\text{S2band}}^{\text{plume}} = L_{\text{B12}} \left(\int_{B12} T_{plume}(\lambda) d\lambda \right) \epsilon_{convolution}$$

...that we can estimate if we model a hyperspectral TOA radiance as follows:

$$\epsilon_{convolution} = \frac{\int_{B12} L_{\text{TOA}}(\lambda) T_{plume}(\lambda) d\lambda}{\left(\int_{B12} L_{\text{TOA}}(\lambda) d\lambda\right)\left(\int_{B12} T_{plume}(\lambda) d\lambda\right)}$$

This concept has been implemented to generate S2 simulated products including methane plumes. Figure 1 illustrates its flow diagram:

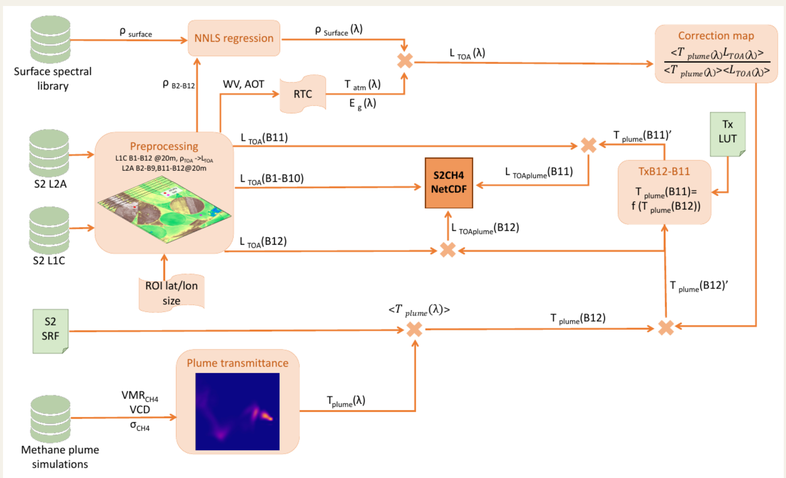

Figure 1: Flow diagram describing the process to generate S2 products with embedded methane plume simulations.

Test against an ideal case (normalisation against same product with no methane plume) proves the importance of the correction.
Tests have shown that T_{atm} has a minor effect but E_g accounts for the major part of the correction. Here surf. ref. has not a relevant impact althought it depends on the specific scene.

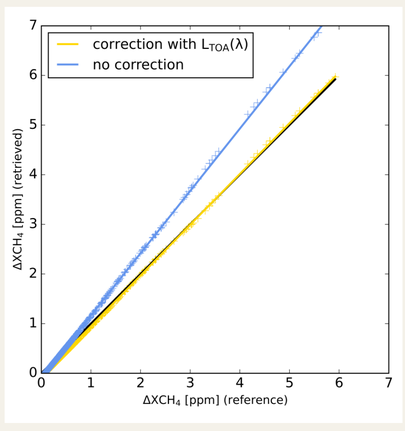

Figure 2: Scatter plot of retrieved versus reference methane enhancement for the Kopeje site (see Left of Figure 3), plume 2 (see Figure 4b) and Q of 10000kg/h. The reference product is the same as the target one with no excess methane to simulate an ideal scenario.

Retrieval methodology

The retrieval is based on a transmittance-proxy

$$\Delta XCH_4 = \frac{-log\left(L/L_{ref}\right)}{\text{AMF} \cdot \sigma_{CH_4}}$$

The small sensitivity of B11 is also accounted during the retrieval.

Automatised process that sets 2σ and detects the plume signal above threshold area with 2-pixel connectivity. The threshold for the minimum #pixel considered as a representative area is set manually (~40 pixels). It is currently the major limitation for an objective approach of the detection limit.

IME is calculated from the sum of detected pixel and conversion to equivalent methane mass. The Q is related to the IME as:

$$Q = \frac{U_{\text{eff}} \cdot \text{IME}}{L}$$

Sites and datasets

2 sites representative of heterogeneous and homogeneous conditions for the detection of methane emissions.

- Kopeje (Turkmenistan) @ latlon= (38.49383º, 54.19767º)
- Permian basin (USA) @ latlon= (31.72070º, -102.28663º)

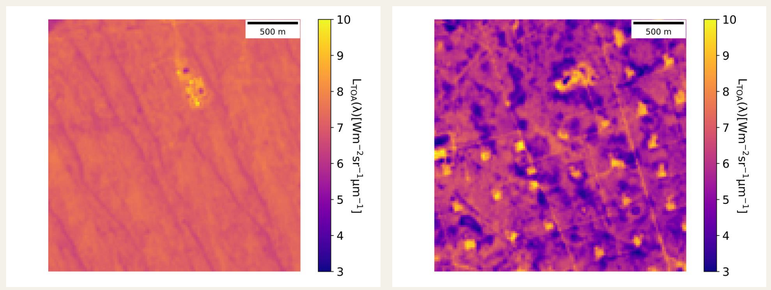

Figure 3: TOA radiance for the S2 B12 in the selected areas in (left) Kopeje and (right) Permian.
5 plumes representing different atmospheric transportation snapshots. Simulated with WRF-LES at 50m and 100kg/h flux rates with initial U10 = 3.5m/s.
Resampled at 20m and scaled from 0-20000kg/h flux rates.

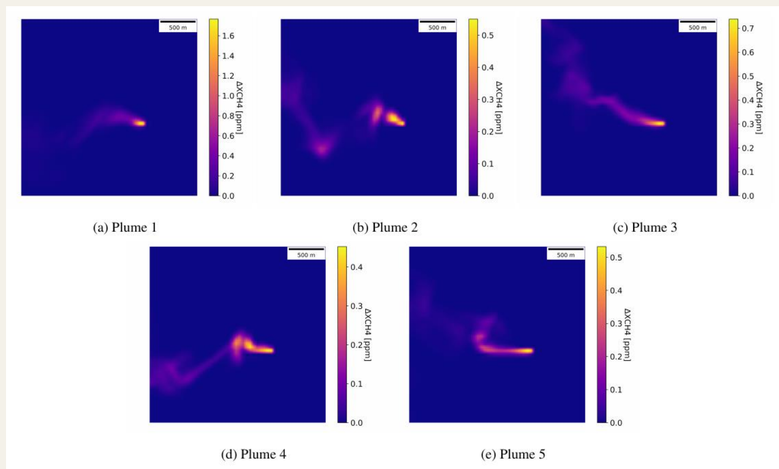

Figure 4: Methane enhancement map of the 5 snapshots condidered in this study.

Q/IME regression

KOPEJE SITE

Figure 5 shows that the Q is overestimated at 20-40% at Q=10000kg/h with a large overestimation of plume 1 (largely due to its high methane concentration). Detection limit ranges from 1500-2500kg/h.

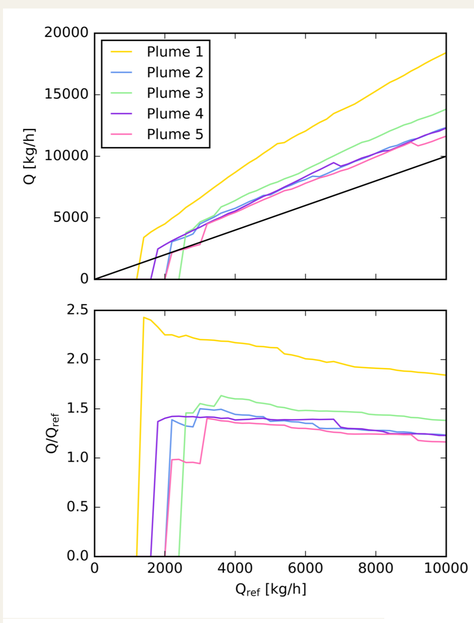

Figure 5: Q regression against reference values for the 5 plumes considered in Figure 4 at the Kopeje site (see Left of Figure 3).

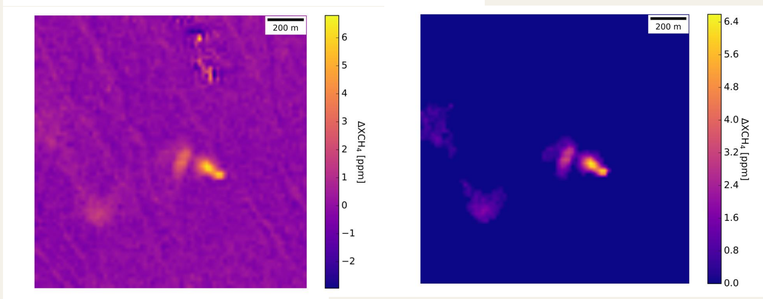

Figure 6: Results for methane plume 2 (see Figure 4b) with flux rate Q=10000kg/h at the Kopeje site (see Left of Figure 3). (Upper left) Enhancement map (Upper right) Masked plume and (Bottom left) scatter plot of the retrieved versus reference enhancement map

PERMIAN SITE

Figure 6 shows that the Q is overestimated at 50-70% at Q=20000kg/h with a large overestimation of plume 1 again. Detection limit ranges from 8000-12000kg/h showing the limited capcaity of detection over heterogeneous scenes.

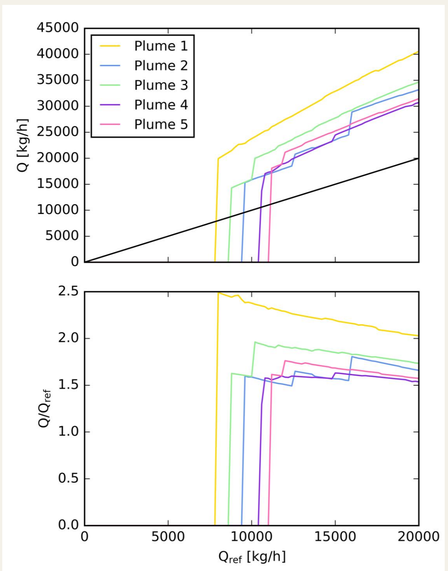

Figure 7: Q regression against reference values for the 5 plumes considered in Figure 4 at the Permian site (see Right of Figure 3).

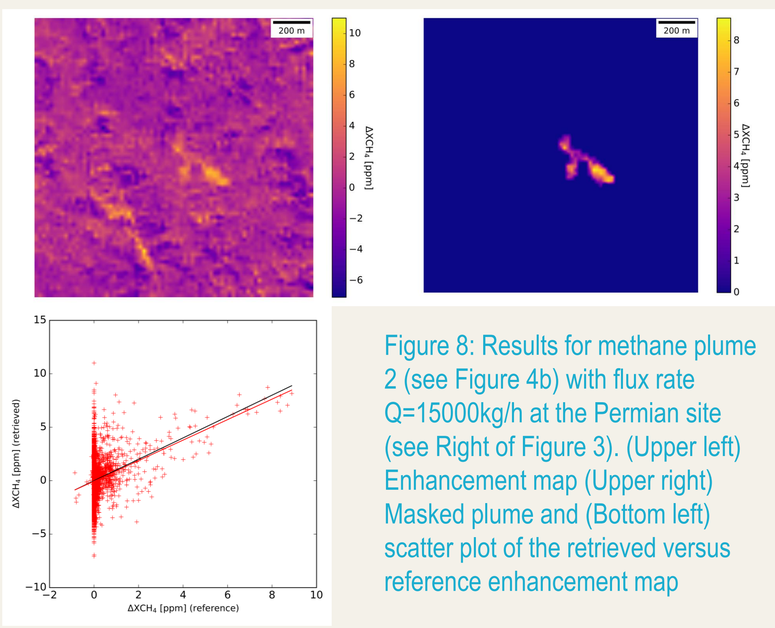

Figure 8: Results for methane plume 2 (see Figure 4b) with flux rate Q=15000kg/h at the Permian site (see Right of Figure 3). (Upper left) Enhancement map (Upper right) Masked plume and (Bottom left) scatter plot of the retrieved versus reference enhancement map

Conclusions

- The study has developed a methane plume simulation methodology for the S2 mission that can be rapidly applied to other optical missions.
- The development of IME-Q regressions has shown great benefits to understand the retrieval performance over different scenes and conditions.
- S2 detection limit for these examples is 1500-2500kg/h in Kopeje and 8000-12000kg/h in Permian.
- Results point towards a Q overestimation of the model.
  - Large disagreement for highly concentrated plumes.
  - Expected disagreement for the rest of plumes (20-40% in Kopeje) with potential U10, modelling or retrieval disagreements.
- Work is ongoing to:
  - better understanding of reference U10 in the simulations.
  - Understand the limitations of the mission and retrieval
  - Potential operational development as an emulator to quantify Q values

References

Varon, D. et al.: High-frequency monitoring of anomalous methane point sources with multispectral Sentinel-2 satellite observations, Atmos. Meas. Tech., 14, 2771–2785, 2021 https://doi.org/10.5194/amt-14-2771-2021.

Ehret, Thibaud, et al.: Global Tracking and Quantification of Oil and Gas Methane Leaks from Recurrent Sentinel-2 Imagery, arXiv preprint arXiv:2110.11832 (2021).

Irakulis-Loitxate, I., et al.: Satellites Unveil Easily-Fixable Super-Emissions in One of the world's Largest Methane Hotspot Regions, EarthArXivPreprint, 202, https://doi.org/10.31223/X56G7R

Cusworth, D. H., et al. : Potential of next-generation imaging spectrometers to detect and quantify methane point sources from space, Atmospheric Measurement Techniques, 12, 5655–5668, https://doi.org/10.5194/amt-12-5655-2019, 2019.

Acknowledgements

Javier Gorroño is funded by the ESA Living Planet Fellowship.

Project funded by ESA AO/1-10468/20/I-FvO-FUTURE EO-1 EO SCIENCE FOR SOCIETY PERMANENTLY OPEN CALL FOR PROPOSALS.
Project web: https://hiresch4.upv.es/

Datasets available here:

Gorroño, Javier; Varon, Daniel; Irakulis-Loitxate, Itziar; Sánchez-García, Elena; Guanter, Luis, 2021, "Sentinel 2 L1C products with simulated methane plumes (S2CH4)", https://doi.org/10.7910/DVN/KRNPEH, Harvard Dataverse, V1