Global tracking and quantification of oil and gas methane emissions from recurrent Sentinel-2 imagery

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Oil and gas methane emissions

The detection of large and frequent methane (CH_4) emissions linked to oil and gas production has raised concerns in the ability of natural gas to effectively reduce greenhouse gas (GHG) emissions as a substitute to coal [1]. Over a 20-year horizon, a CH_4 molecule has a global warming potential close to 80 times larger than carbon dioxide (CO_2) [2]. A large part of the CH_4 emissions could be controlled or avoided, as they come primarily from maintenance operations at oil rigs, pipelines, or well pads, and from equipment failures [3].

Detection and quantification of methane emissions

- Methane absorption model of the observed image I_t at date t from the light intensity I, satellite sensibility s, surface albedo α, atmosphere composition (N gases with their absorption A_i and equivalent optical path length ℓ_i) and the optical path characteristic γ (a function of both the sun azimuth angle and the satellite view angle)

$$I_t = \int I(\lambda)s(\lambda)\alpha(\lambda)e^{-\gamma\sum_{i=0}^{N} A_i(\lambda)\ell_i}e^{-\gamma A_{CH4}(\lambda)\ell_{leak}}d\lambda. \quad (1)$$

- Background image I_{bg} estimation from previous observations (I_i)

$$I_{bg} = \sum_{i=0}^{t-1} w_i I_i \quad \text{such that} \quad (w_i) = \underset{(w_i)}{\arg\min} \left\| I_t - \sum_{i=0}^{t-1} w_i I_i \right\|^2.$$

- Methane excess $\Delta\Omega$ for the pixel p using the band 12 of Sentinel-2 and the model from (1).

$$\Delta\Omega(p) = \underset{\ell_{leak}}{\arg\min} \left\| \frac{I_t(p)}{I_{bg}(p)} - \frac{\text{simu\_atmosphere}(\ell_{leak})}{\text{simu\_atmosphere}(0)} \right\|_2^2.$$

- Emission rate Q estimation [4] using the effective wind U_{eff}, area/pixel A, plume length L and plume mask $\mathcal{M}$

$$Q = A\frac{U_{eff}}{L}\sum_{p\in\mathcal{M}} \Delta\Omega(p),$$

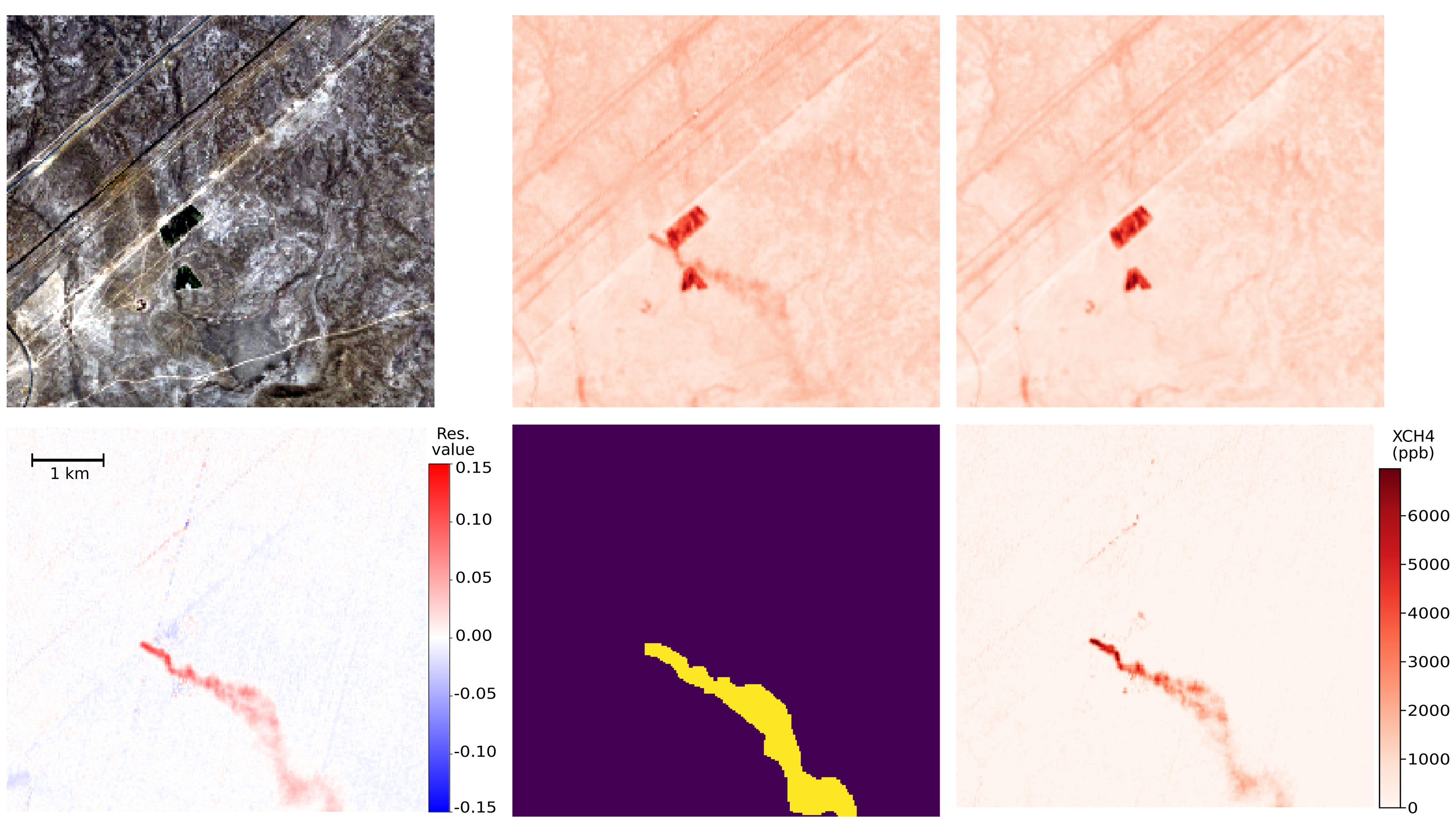

Figure 1: Visualization of each step of the detection and quantification method. From left to right, top to bottom: the Sentinel-2 image of the location (only the RGB channels are shown), the log band ratio corresponding to the image, the predicted background model, the residual showing the plume, the mask corresponding to the detected plume and the associated quantification in ppb.

References

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[2] P. Forster et al., "The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity," in Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Intergovernmental Panel on Climate Change, Ed. Cambridge University Press, 2021

Global monitoring of oil and gas sites

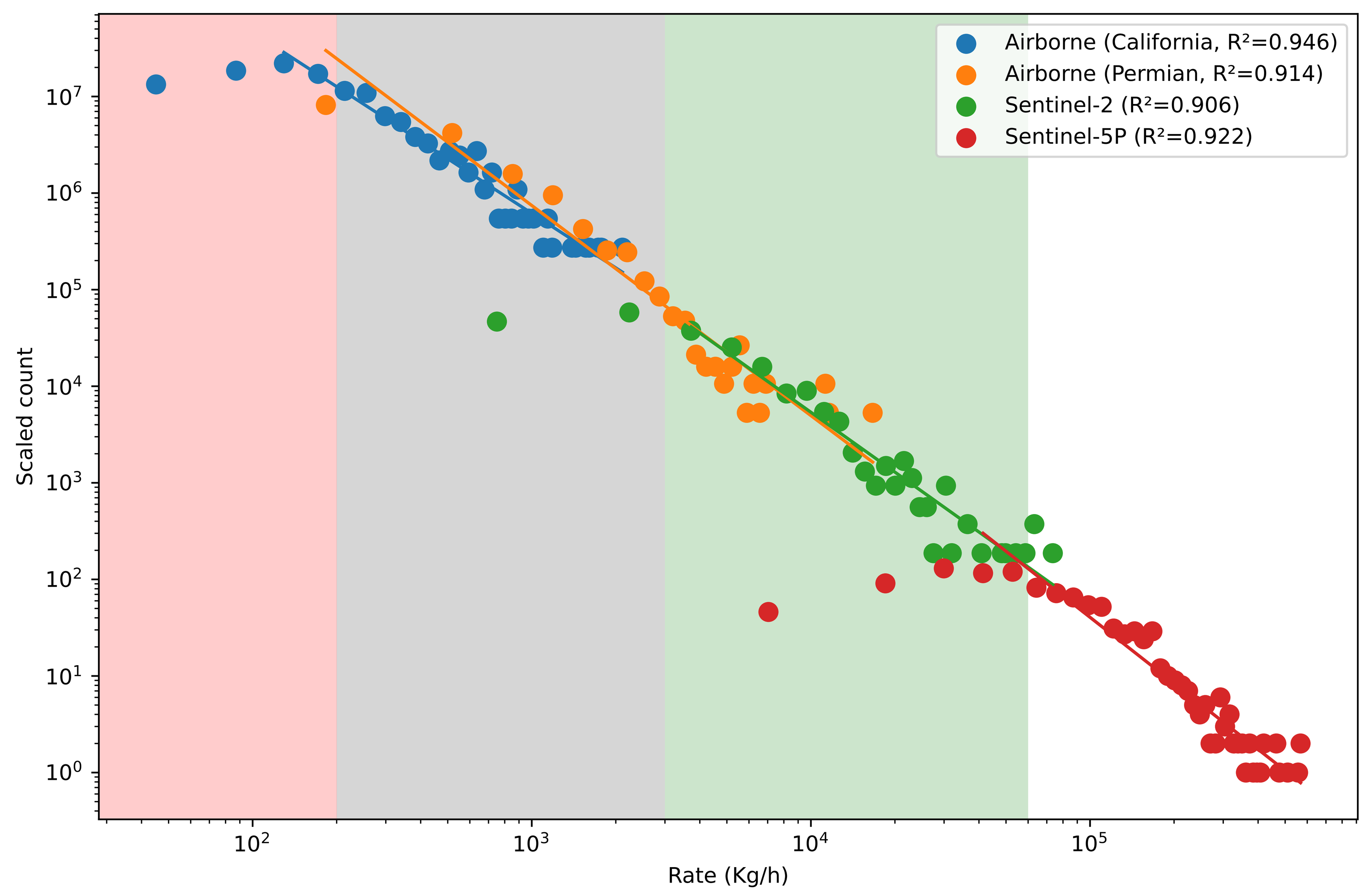

Figure 2: Power law plot of Sentinel-5P [5] and Sentinel-2 events, together with airborne campaigns over California [6] and the Permian [7]. Counts are scaled to match in common detection zones. Since data is consistent across the different sources used for the study, this shows that at a global scale large event observation might be a good proxy indicator for smaller but unobserved events (corresponding to the green region). The grey region represent the region where the model should still be valid. It is however unlikely that the power law model is valid in the red region.

Monitoring of a specific site using multiple satellites

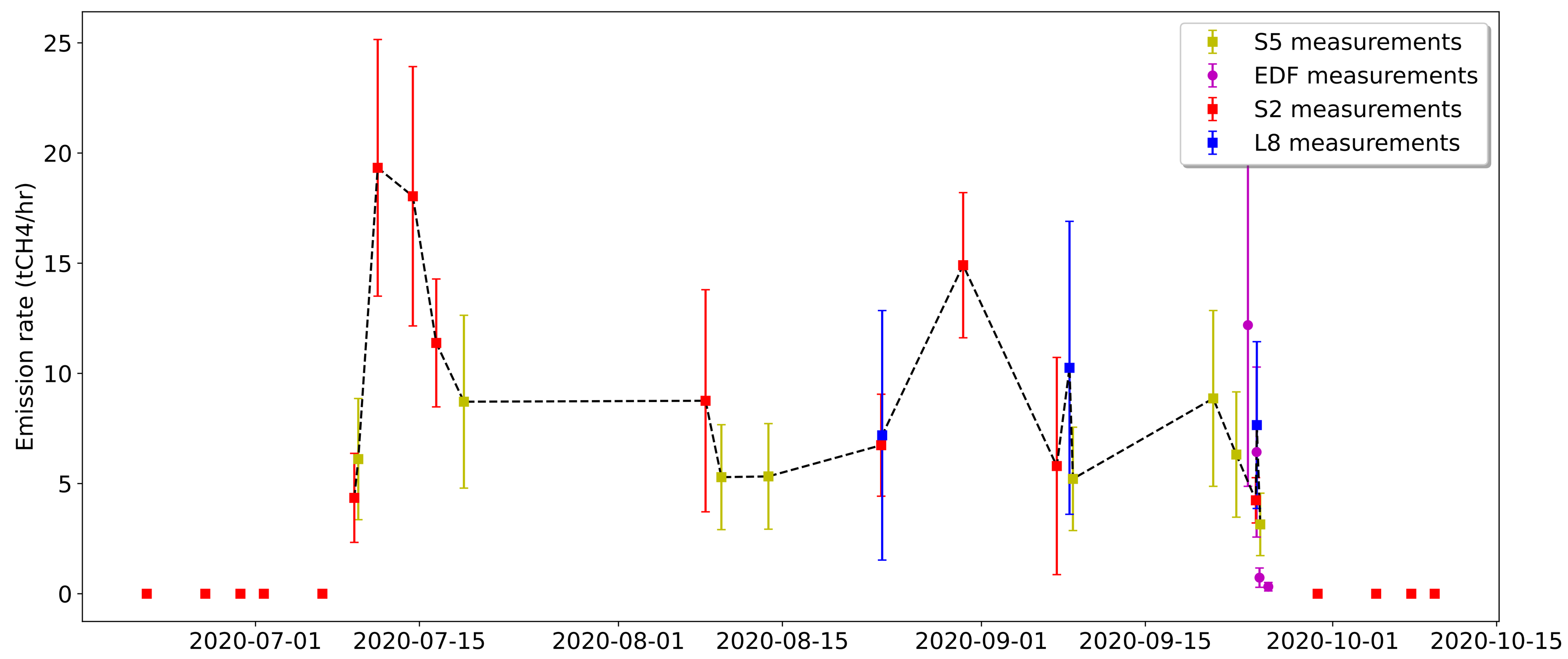

Figure 3: Emission rates measured during an event in the Permian basin occurred during the summer of 2020 (estimated latitude and longitude: 31.7335, -102.0421). The plot combines estimates obtained from Sentinel-2, Landsat-8, Sentinel-5P and from Scientific Aviation flights (with their respective uncertainty corresponding to the standard deviation of the estimates). All of these estimates show that the emission started more than two months earlier than it was initially reported by the EDF campaign. Moreover, these estimates seems to be consistent across sources.

References (continued)

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