CO2Image retrieval studies and performance analysis

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Introduction

Mission overview

- National satellite mission (DLR), providing public data
- Complementary to other missions such as CO2M
- Planned for launch in 2026 (currently in Phase B2)

Scientific objective:

- *Anthropogenic* point source emissions of CO_2 [3] and CH_4
- Carbon dioxide (CO_2) quantification >1 Mt/y (detection >0.3 Mt/yr)
- Methane (CH_4) quant. >300 kg/hr (detec. >100 kg/hr)

Technical specifications:

- Push-broom grating spectrometer *COSIS*
- High spatial resolution (50 m×50 m)
- Short-Wave IR (SWIR) spectra from 1972–2400 nm
- Moderate spectral resolution 1.30 nm @ FWHM [4]

BIRRA — Beer InfraRed Retrieval Algorithm

Nonlinear least squares: $\min_x \|\boldsymbol{y} - \boldsymbol{F}(\boldsymbol{x})\|^2$

$$\boldsymbol{F}(\boldsymbol{x}) = r(\nu)/\pi \cos\theta\, I_{\text{sun}}(\nu) \exp\left[-\sum_m \alpha_m \tau_m(\nu)\right] \otimes \mathcal{S}(\nu, \gamma, \ldots) + b$$

τ_m molec optical depth; $\mathcal{S}$ ISRF; θ SZA; b baseline

$$\boldsymbol{x} \in (\boldsymbol{r}, \boldsymbol{b}, \boldsymbol{\alpha}, \gamma, \delta, \ldots).$$

- BIRRA infers information from SWIR radiance intensity $\boldsymbol{I} = \boldsymbol{F}(\boldsymbol{x})$
- SWIR observations sensitive down to the tropospheric boundary layer
- State vector $\boldsymbol{x}$ contains geophysical parameters
- *Py4CAtS* line-by-line (lbl) forward model [2]
- Successfully applied to space- and airborne sensors (e. g. [1])

COSIS spectra & L1→L2 processing

Steps include:

- Simulate high-resolution, at-aperture radiance (Py4CAtS)
- Derive total instrument signal and compute photo signal
- Apply COSIS radiometric calibration
- Convert signal to spectral radiance at instrument resolution

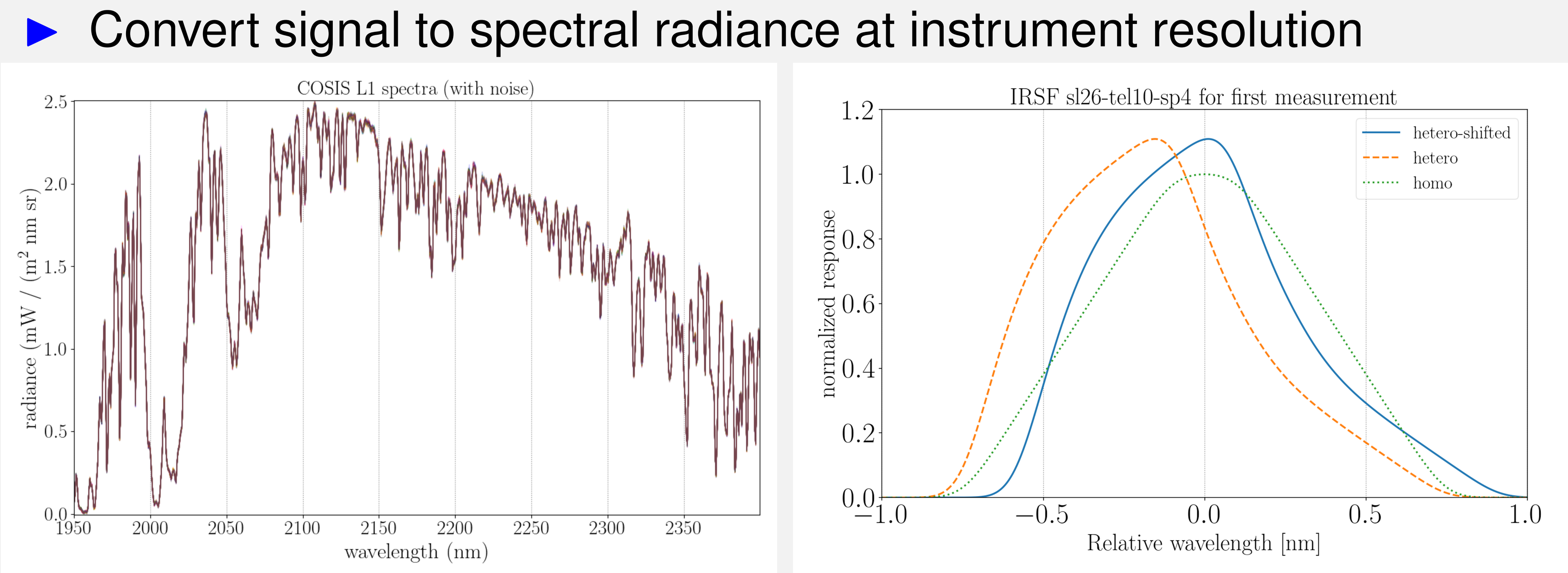

Fig. 1: (Left) Example of noisy COSIS radiance spectra. **(Right)** Nominal spectral response with impact of scene heterogenity on effective ISRF (see Fig. 3).

Input for the retrieval includes:

- *Synthetic* COSIS observations
- Instrument's *spectral response* (e.g. Gauss⊛Box or tabulated)
- Spectroscopic line data such as HITRAN or GEISA
- Atmospheric model data such as $p(z)$, $T(z)$
- Priors for *molecular concentration profiles* $n(z)$

Impact of SNR

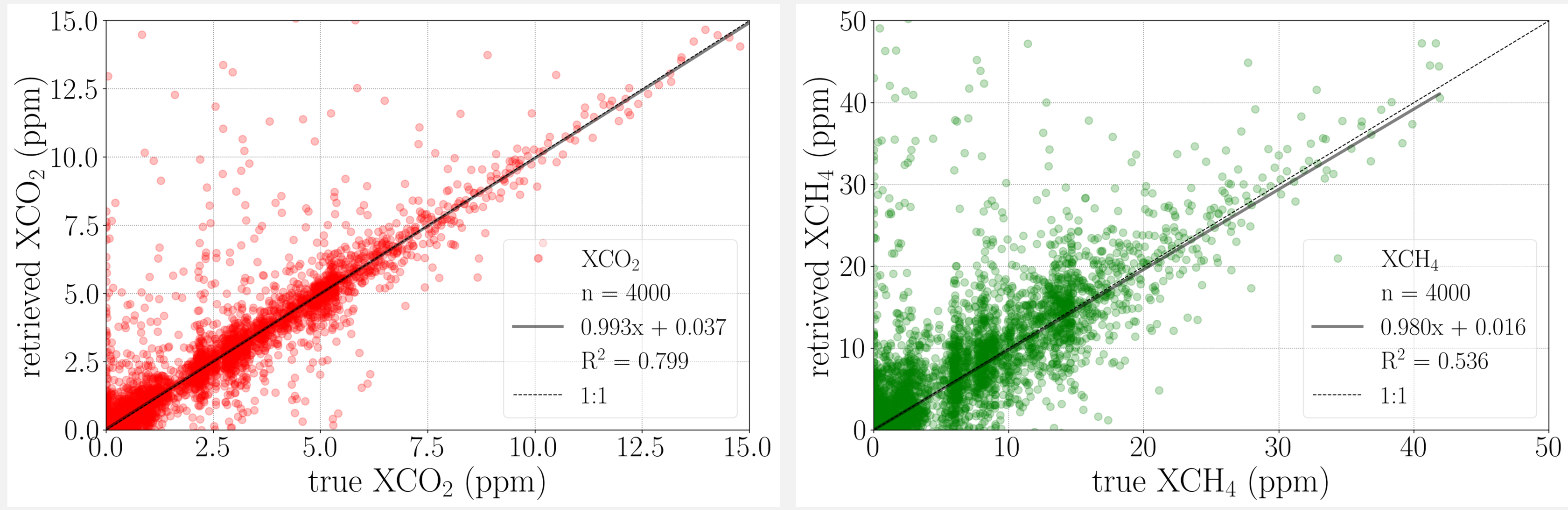

Fig. 2: Retrieval of enhancements of **(Left)** CO_2 and **(Right)** CH_4 with spread induced by COSIS instrument noise.

Impact of heterogeneous scene albedo

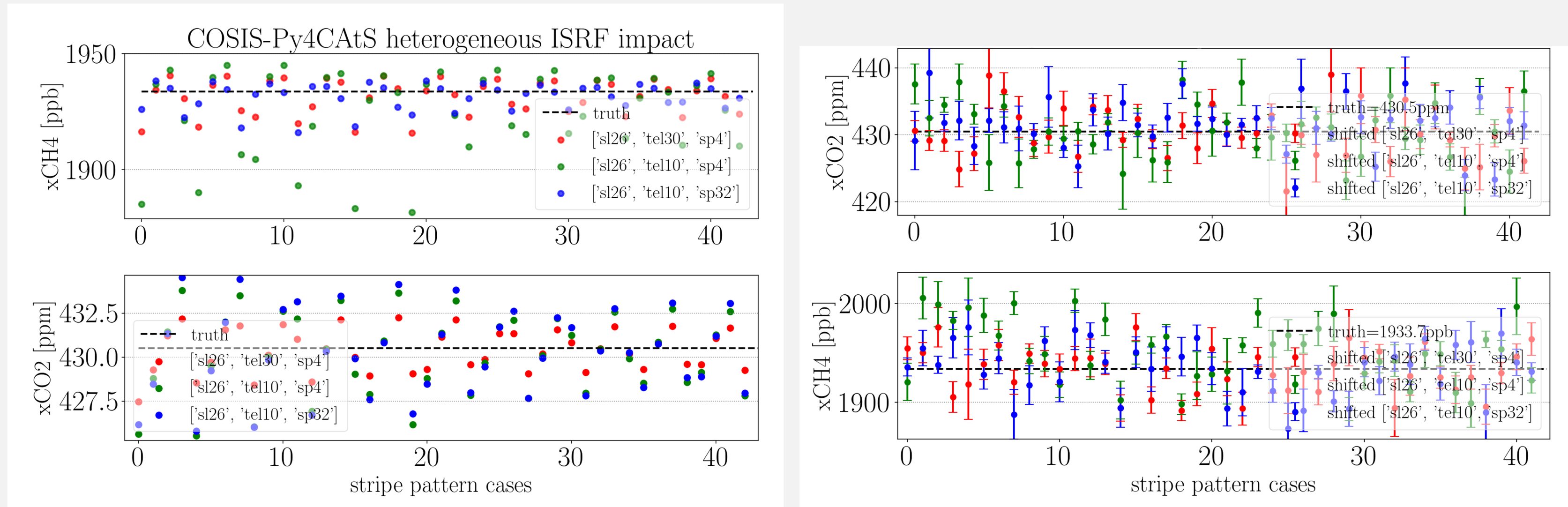

Fig. 3: Heterogeneous scenes (*light/dark albedo patterns*) and their impact for different ´blur functions´ (see Fig. 1): *telescope* (front optics), *slit*, and *spectrometer* — default is *sl26 tel10 sp4* (green). Induced error for retrievals **(Left)** w/o noise and **(Right)** with COSIS noise.

2D concentration fields

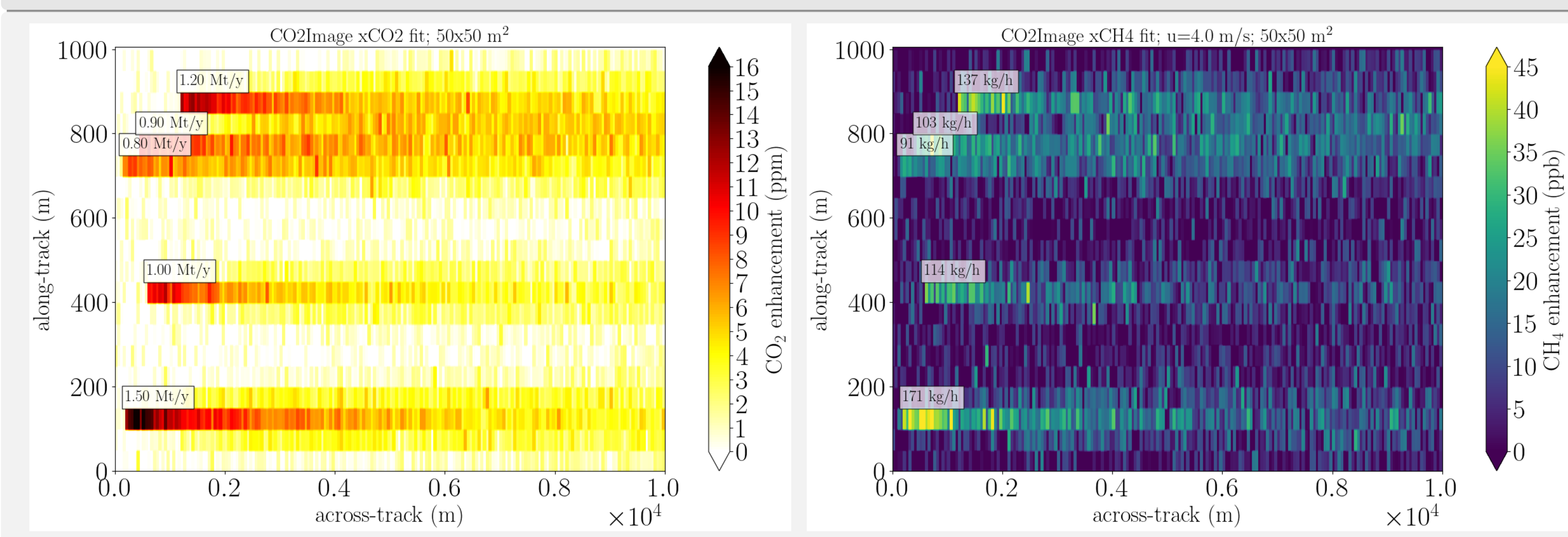

Fig. 4: *Gaussian plume model* for concentrations from point-like sources with various emissions for wind speed 4 m/s. Retrieval output for **(Left)** column integrated CO_2 and **(Right)** CH_4 mole fractions.

Vertical concentration profiles

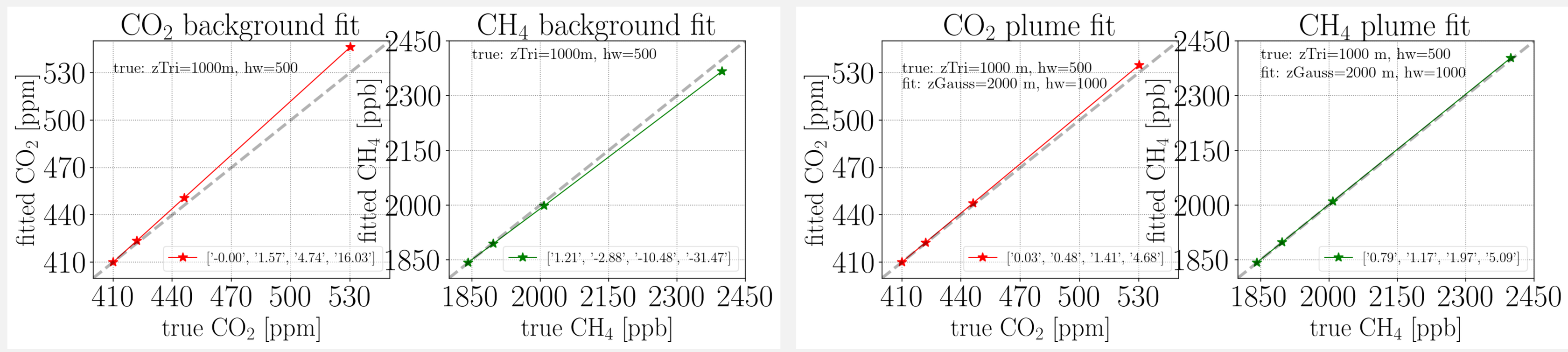

Fig. 5: Error of inferred total columns by scaling a wrong initial guess profile. **(Left)** Background profile fit versus **(Right)** plume profile fit.

References:

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