Methane and carbon dioxide retrievals from airborne and space-borne observations in the short-wave infrared

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Introduction

- CO_2 and CH_4 trace gases affect the global climate
- Anthropogenic emissions surge atmospheric concentrations
- Short-Wave IR spectra to infer molecular concentrations
- SWIR observations sensitive down to the tropospheric boundary layer ⟶ allows for sources and sinks analysis

Level 1⟶2 Processing

- Molecular concentrations from radiance spectra
- Forward model is represented by radiative transfer model
- Mathematical inversion by means of least squares fitting

Input

- Measured radiance spectra from, e.g., TROPOMI, the OCOs, or GOSAT
- Spectroscopic data from, e.g., SEOM–IAS [1], GEISA [2], or HITRAN [4]
- Atmospheric data and initial guess values
- Information on the instrument's ISRFs, BDPM, ...
- Auxiliary information such as terrain elevation, cloud-masks, ...

Output

- Fitted state vector elements along with error estimates
- Converged model spectrum with spectral residuals

BIRRA — Beer InfraRed Retrieval Algorithm

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

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

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

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

- Py4CAtS forward model based on GARLIC [6]
- BIRRA was originally developed for SCIAMACHY nadir CO, CH_4 [3, 5]

GOSAT — Greenhouse Gases Observing Satellite

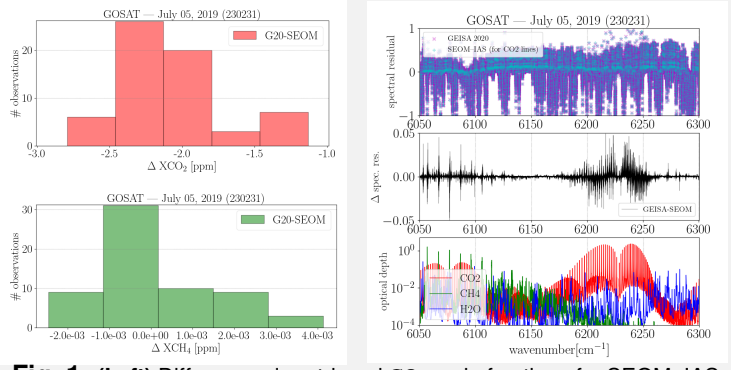

Fig. 1: (Left) Differences in retrieved CO_2 mole fractions for SEOM–IAS and GEISA 2020 spectroscopies. **(Right)** Spectral residuals in CO_2's weak absorption band.

HySpex — Hyperspectral Imaging Sensor

Local CH_4 enhancements:

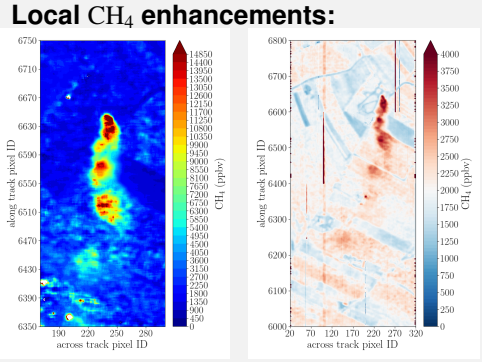

Fig. 2: Methane plume over a coal mine ventilation shaft observed by airborne HySpex. **(Left)** Single-window CH_4 retrieval with background-statistics. **(Right)** Multi-window retrieval.

OCO-2 & OCO-3 — Orbiting Carbon Observatory

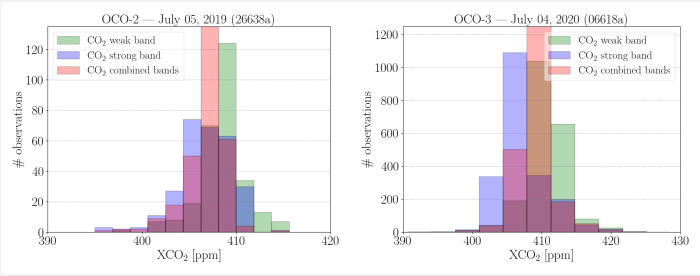

Fig. 3: Retrieved CO_2 for OCO-2 and OCO-3 (single orbit).

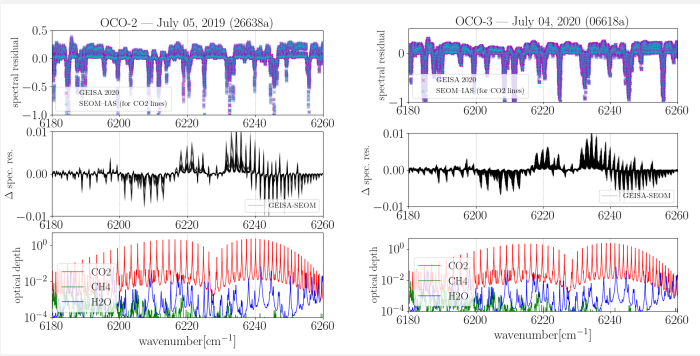

Fig. 4: Spectral residuals in the weak CO_2 absorption band for SEOM–IAS and GEISA 2020 line lists.

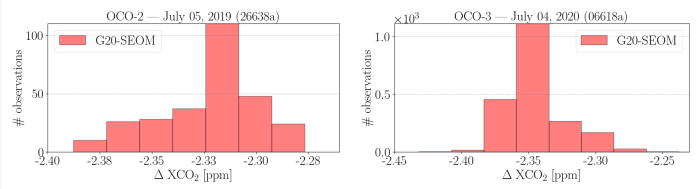

Fig. 5: Spectroscopic impact on CO_2 mole fractions.

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