HyperGas 1.0: A Python package for analyzing hyperspectral data for greenhouse gases from retrieval to emission rate quantification

Xin Zhang[1], Joannes D. Maasakkers[1], Tobias A. de Jong[1], Paul Tol[1], Frances Reuland[2], Adam R. Brandt[2], Eric A. Kort[3], Taylor J. Adams[3], and Ilse Aben[1,4]

[1]SRON Space Research Organisation Netherlands, Leiden, 2333 CA, The Netherlands
[2]Department of Energy Science & Engineering, Stanford University, Stanford, California 94305, United States
[3]Department of Climate & Space Sciences & Engineering, University of Michigan, Ann Arbor, MI 48109, USA
[4]Department of Earth Sciences, Vrije Universiteit Amsterdam, Amsterdam, 1081 HV, The Netherlands

Correspondence: Xin Zhang (xin.zhang@sron.nl)

We thank the editor for careful reading of our article. The individual corrections suggested are addressed below. The editor's comments will be shown in ***black italic***, our response in **normal font**, and changes made to the paper are shown in **blue** block quotes. Unless otherwise indicated, page and line numbers correspond to the original manuscript, while reference numbers follow the new order.

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1 Editor Comments

(1) *Please place the in text URLs (e.g., Line 41) with in text citations (see https://www.geoscientific-model-development.net/submission.html*

Thank you for the suggestion. We have replaced all text URLs by references.

> Existing open-source tools, such as mag1c **(Foote et al., 2020)** and emit-ghg **(Brodrick et al., 2026)**, are restricted to a single HSI or data format, while frameworks such as ddeq (Kuhlmann et al., 2024) focus mainly on source quantification rather than a complete end-to-end workflow.
>
> For PRISMA, the L1 data are obtained from the PRISMA Portal **(Italian Space Agency, 2026)**; for EnMAP, these come from the EOWEB GeoPortal **(German Aerospace Center (DLR), 2026)**; and for EMIT, users can download L1 data from NASA Earthdata **(Green, 2022)**.
>
> *HyperGas* also supports two other datasets available through the cartopy feature interface **(Elson et al., 2024)**: the Global Self-consistent, Hierarchical, High-resolution Geography (GSHHG) database and the 10-m Natural Earth dataset.
>
> The algorithm is applied through the *Spectral Python (SPy)* package **(Boggs et al., 2022)**, which supports the matched filter method.

(2) *Line 83: Please explain what is meant by "'xarray.DataArray(bands, y, x)' format" as it may not be clear to readers.*

We have added the dimension definitions.

> Because HSI file formats vary across different products, we have integrated multiple HSI readers into another Python package named *Satpy* (Raspaud et al., 2025), ensuring a standardized data loading interface that returns **a three-dimensional data array (`xarray.DataArray`) organized as (bands, y, x), where the first dimension represents spectral bands and the remaining two represent spatial coordinates (Hoyer and Hamman, 2017)**.

(3) *Please correctly punctuate the equations (see e.g., https://www2.math.uconn.edu/ khlee/math2784s10/writingtips.pdf).*

Thank you for the link of writing tips. We have corrected several expressions and added "period" or "comma" at the end of lines.

> The modeled spectrum affected by the gas absorption (x_m) is defined according to the Beer-Lambert law:

$$x_m = x_r e^{-k\Delta X}, \quad (1)$$

where $\boldsymbol{x_r}$ is the reference spectrum and $\boldsymbol{k}$ is a unit absorption spectrum.

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The radiance spectrum ($\boldsymbol{L}$) considers two scenarios: a null hypothesis $\boldsymbol{H_0}$ representing background conditions, and an alternative hypothesis $\boldsymbol{H_1}$ indicating the presence of enhanced gas concentrations (Thompson et al., 2015).

$$\boldsymbol{H_0 : L \sim \mathcal{N}(\mu, \Sigma); \quad H_1 : L \sim \mathcal{N}(\mu + \Delta X t, \Sigma).} \tag{2}$$

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The optimal estimate of the enhancement factor $\boldsymbol{\Delta X}$ is obtained through maximum likelihood estimation:

$$\boldsymbol{\Delta X = \frac{(t-\mu)^T \Sigma^{-1} (L-\mu)}{(t-\mu)^T \Sigma^{-1} (t-\mu)}.} \tag{3}$$

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Therefore, *HyperGas* provides the lognormal matched filter method which applies logarithms to both sides of Eq. (1):

$$\boldsymbol{\ln(x_m) = \ln(x_r) - k\,\Delta X.} \tag{4}$$

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Then the optimal estimate of $\boldsymbol{\Delta}$X is derived as below:

$$\boldsymbol{\Delta X = \frac{(k-\tilde{\mu})^T \tilde{\Sigma}^{-1} (\tilde{L}-\tilde{\mu})}{(k-\tilde{\mu})^T \tilde{\Sigma}^{-1} (k-\tilde{\mu})},} \tag{5}$$

where $\boldsymbol{\tilde{\mu}}$ is the mean log background radiance, $\boldsymbol{\tilde{\Sigma}}$ is the covariance matrix of the log background radiance, and $\boldsymbol{\tilde{L}}$ is the log radiance spectrum.

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We apply the IME method as the default method to estimate gas emission rates ($\boldsymbol{Q}$ in kg h^{-1}):

$$\boldsymbol{Q = \frac{\mathrm{IME} \cdot U_{\mathrm{eff,IME}}}{L},} \tag{6}$$

where IME is the total gas mass enhancement (kg) within the plume mask, $\boldsymbol{L}$ (m) is the square root of the plume area, and $\boldsymbol{U_{\mathrm{eff,IME}}}$ is the effective wind speed (m/s).

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The column mass enhancement $\boldsymbol{\Delta\Omega}$ is derived from $\boldsymbol{\Delta}$X:

$$\boldsymbol{\Delta\Omega = \frac{M_X}{M_a}\Omega_a \Delta X,} \tag{7}$$

where M$_{\boldsymbol{X}}$ and M$_{\boldsymbol{a}}$ are the molar masses (kg mol$^{\boldsymbol{-1}}$) of gas $\boldsymbol{X}$ and dry air (28.96 $\times$ 10$^{\boldsymbol{-3}}$ kg mol$^{\boldsymbol{-1}}$), and $\boldsymbol{\Omega_a}$ is the column of dry air (kg m$^{\boldsymbol{-2}}$).

...

Here, the source rate is estimated as the product of the cross-plume gas enhancement integral and a different effective wind speed ($\boldsymbol{U_{\text{eff},\text{CSF}}}$):

$$\boldsymbol{Q = U_{\text{eff},\text{CSF}} \int_a^b \Delta\Omega(x,y)\, dy.} \tag{8}$$

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