

Review of “The GHGSat-D imaging spectrometer” by Jervis et al.

This paper outlines the design, retrieval algorithm, and performance of the GHGSat-D instrument, a Fabry-Perot spectrometer to measure methane columns at high spatial resolution (~50 m). The paper is laid out and written well. The instrument seems to be a clever design, though this first instrument appears to suffer from some serious instrument artefacts, as are described in the paper.

I recommend publication after minor revisions as outlined below. My main suggestion is to include more information on the retrieval algorithm and the implicit assumptions of your forward model and prior uncertainties.

Specific Comments

P2, L25: “...which limits their detection sensitivity.” Can you state any more quantitatively what the detection limit of these coarse spectral resolution instruments might be? Even providing a range would be helpful to the non-expert (like me).

P7, L20: Please state which version of HITRAN you use (2012, 2016, etc) and if you have done any sensitivity tests to see the effect on your retrievals using different versions.

P7, L21: It’s becoming “standard” in our community to use the “Geoff Toon” solar transmittance spectrum. Mainly because everything thinks Geoff is incredibly careful and pays more attention to detail than anyone else. In any case, typically the best residuals are yielded when you use this linelist. It may not matter much for your application, but just FYI. (https://mark4sun.jpl.nasa.gov/toon/solar/solar_spectrum.html, I recommend 2016, disk-integrated spectrum). You have to multiply by the solar continuum yourself.

P8, L25: I do not understand why it is so computationally expensive. Your forward model is literally $F_{\text{sun}}(\lambda) * \mu_0 * \text{Albedo}(\lambda) / \pi * \exp(-m * \tau(\lambda))$, where m is the airmass factor. Nearly all the work is done in calculating $\tau(\lambda)$:

$$\tau(\lambda) = \tau_{\text{ch4}}(\lambda) + \tau_{\text{h2o}}(\lambda)$$

$$\tau_{\text{ch4}}(\lambda) = \text{Sum}_{i=1..N_{\text{layers}}} \{ \sigma_{\text{ch4}}(i, \lambda) * u_{\text{ch4}}(i) \}$$

$$\tau_{\text{h2o}}(\lambda) = \text{Sum}_{i=1..N_{\text{layers}}} \{ \sigma_{\text{h2o}}(i, \lambda) * u_{\text{h2o}}(i) \}$$

The σ ’s can be calculated once for the whole scene (unless you’re retrieving surface pressure or temperature, which I do not think you are).

P9, L5: Is retrieving d analogous to retrieving the wavelength shift and stretch for a standard GOSAT-type retrieval? If so, say so.

P9, Sect 4.5: It is hard to tell what you are doing without more information – could you please include a table that lists your state vector parameters, the source of your prior information or the prior values themselves, and the prior uncertainty you assume? Also, do you assume any spatial pixel-to-pixel correlations in your prior covariance matrix? Do you retrieve a scale factor

for CH₄, CH₄ in the boundary layer only, or a full profile in some way? Etc. {It looks like you retrieve “VCD”. But do you spread this equally in the vertical? I.e., you might have sensitivity to HOW you retrieve CH₄. What if you put it all in the boundary layer? Because the gas absorption cross section is different down there, I expect it will affect your results in a small way.}

Also, I’m surprised you can use AIRS. Plus AIRS will die someday. And all the decent NWP models assimilate it anyway. Why not just use GEOS5 or ECMWF model output?

Additionally, where does your prior surface pressure and temperature profile come from? Do you assume a fixed surface elevation across the field of view, or do you use a high-res DEM to get the surface elevation for each pixel, and a hypsometric adjustment to determine the prior surface pressure of each pixel? You don’t say anything about if you can do this over complex topography or not.

Finally, can you say how many iterations this takes typically, and how long the retrieval takes for one full scene of data (on however many CPUs you typically use).

Same paragraph – do you have any way to test for and remove bad pixels? You could also attempt to include a stray light parameter or two in your forward model. You’d probably have the information content to solve for it.

P12, L10: I’m really surprised by this 6.5% theoretical (noise-driven) error. This is something like 120 ppb of methane. TROPOMI has errors more on the order of 10 ppb. And your number assumes PERFECT knowledge of temperature, water vapor, surface albedo, surface pressure, spectroscopy, instrument, etc. Literally everything but the instrument noise, which isn’t bad; you list radiance SNR = 200 at these conditions. I have a feeling that if I wrote my own simple Beer’s law forward model in wavelength space, and put an SNR of 200 per channel, using your spectral resolving power, I’d get a posterior uncertainty of less than 1%. What am I missing? In other words, can you say why this noise-driven uncertainty is so large compared to what a grating instrument with a similar SNR and spectral resolution would achieve?

Technical

L26: “reported in (Varon et al., 2019)” should be “reported in Varon et al. (2019)”. Use `\citet` instead of `\citep` in LaTeX. Similar for P3, L13-15 and various places throughout the document.