

Interactive comment on “Chlorophyll fluorescence remote sensing from space in scattering atmospheres: implications for its retrieval and interferences with atmospheric CO₂ retrievals” by C. Frankenberg et al.

C. Frankenberg

christian.frankenberg@jpl.nasa.gov

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Comments in red, response in black

This is an interesting and well-written paper, but it also raises some questions, and some irritations as well:

We appreciate this short comment on our manuscript and would like to clarify some statements up front as they seem to have caused irritations and concurrent emotional reactions, which is certainly not our intention. First of all, we are not following any

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political or programmatic position but try to stay focused on science. Any comment should do the same. We fully acknowledge the FLEX mission concept and think it the general rationale behind it is a great idea, which will eventually result in future missions targeting fluorescence. The scientific community as a whole, irrespective of the field, owes great debt to the originators of FLEX and the fluorescence field in general (going back decades). We are fully aware of all the previous hard work we now benefit from, we do not at all disregard it.

P2489 L5: What is exactly meant by a "full-physics" algorithm? In which cases can an algorithm be considered full-physics and when not?

It means that all processes in the atmosphere are modeled based on the physical principles of radiative transfer and no parameterizations. It may be jargon typically used in our community, so we will clarify it in the text.

P2489 L10: "as they are mostly constrained". Is "constrained" the right term here? Aerosol properties are not constrained by strong absorption features. Did you mean that the strong absorption features help in the retrieval of aerosol properties?

Indeed, this is the whole point of using the O₂ A-band for greenhouse gas missions. There is a multitude of papers out there showing this (of which we reference a substantial amount). With regard to fluorescence scattering, our GRL paper (Frankenberg, Butz, Toon: Disentangling chlorophyll fluorescence from atmospheric scattering effects in O₂ A-band spectra of reflected sun-light. Geophys. Res. Lett. (2011) vol. 38 pp. L03801) shows Jacobians with respect to scattering properties, which should clarify this point. In fact, we believe that a lot of the confusion is just because of the point mentioned here.

P2490 L18: "saturated". I would not say that this band around 765 nm is saturated, as this is not really the case. Try to rephrase this more accurately.

We consider the O₂ A-band highly saturated, at least in the core of the strong lines

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using high resolution spectra where column optical densities exceed multiple hundreds. Direct solar observations from the ground yields zero transmission (within the noise) in the core of the lines, which is, in our definition, saturated.

P2490 L26: "we have shown". In my opinion you have not shown this. You may have suggested that it might be difficult, but you have not demonstrated that it is impossible. For this, it would be necessary to carry out a complete sensitivity analysis, showing quantitatively the ill-posedness of the retrieval regarding this issue, and this was not done in that paper.

The ill-posedness of the problem considering the O2 A-band alone (roughly 755-773nm) was already shown in Frankenberg, Butz, Toon: Disentangling chlorophyll fluorescence from atmospheric scattering effects in O-2 A-band spectra of reflected sun-light. *Geophys. Res. Lett.* (2011) vol. 38 pp. L03801. It was shown that the fluorescence signal is not linearly independent of the Jacobians with respect to scattering properties, which is by definition ill-posed.

P2492 L1: retrievec → retrieved

em Will be changed, thanks.

P2492 L3: Please include some comment on what has to be done if fluorescence is not isotropic, which appears as a result from simulations with canopy fluorescence models. Eq. (1): This means that the shape of the canopy fluorescence spectrum is fixed, where it is known that the ratio of A1 and A2 varies. Then it would be interesting to know the influence of A1 on the spectrum in the region around 755 nm!

Our retrieval scheme is flexible and we can fit the slope of the Fs spectrum in addition to Fs itself. However, our simulations have shown that the fit of the slope is not very stable. For the main purpose of our paper (impact on XCO2), the slope is a 2nd order effect, especially given that we only consider a relatively small wavelength range.

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P2494 L8: chlorophyll emission → chlorophyll fluorescence emission

Will be changed, thanks.

P2494 : Could you please indicate here on this page which spectral window was used exactly for the retrieval?

Will do so, thanks (it is identical to the ones used in the previous two GRL papers).

P2498 L18: Please avoid insinuations about the FLEX mission which suggest that only oxygen absorption bands would be used for the retrieval of Fs. This is not true. FLEX is expected to use the whole 500 - 780 nm region, and how Fs will be retrieved is still under investigation, but it will certainly not only use the O2 absorption bands!

We will delete "and suggested for the FLEX mission". To quote the FLEX ESA paper: "Unfortunately, the spectral absorption lines in the original solar spectrum are too weak and too narrow to be used for the red/near-infrared spectral range, which is of interest for chlorophyll fluorescence retrievals." Concerning the FLEX measuring principle, we acknowledge that trade-offs must generally be done in the definition of mission specifications, and that FLEX has chosen to have what could be a more complicated retrieval approach at the expense of covering a wider spectral range. Our references to FLEX were only intended to discuss the feasibility of retrieving Fs in O2 bands, which is of central interest to this paper. Again, no political or programmatic position is behind these references. In addition, we clearly acknowledged the difference in the FLEX concept (using a wider range): "A combination of O2 A and B-bands, such as envisioned in the FLEX mission concept, would be preferred if spectral resolution is not high enough to exploit Fraunhofer line features (Guanter et al., 2010; Sanghavi et al., 2011)." Thus, we believe to have done due diligence but will, as mentioned, delete the FLEX reference.

P2501 L15: "The most appropriate way ...". I disagree with this statement, and I think that your own results point in another direction, since your results and those presented

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in Guanter et al. (2010) suggest that using a wider window including the O2-A region as well as the region around 755 nm would combine the best of both worlds. I do not understand why you did not investigate this possibility, and why you keep claiming that using only the solar Fraunhofer lines would be sufficient or even the "most appropriate way". You mention a number of problems associated with Fs retrieval in the O2-A band, but using only solar Fraunhofer lines as you suggest also has its problems, which you should address as well, such as spectral shifts between library solar spectra and measured data, radiometric calibration problems, non-linearity, zero-level offset, et cetera. How about solar activity changes? Doppler shifts? What is the combined effect of all these factors on the final precision of Fs retrieval in this way?

With all due respect but we disagree. What we clearly show in this paper here is that Fs retrievals are much more stable if you don't use the O2 lines in addition to the Fraunhofer lines. The disadvantages by far outweigh the potential advantages. As mentioned before and clearly stated in our manuscript, it may be different if you use a combination of the O2 A and B-bands together. As for your skepticism regarding Fraunhofer lines:

- *All of the above point are not specific to Fraunhofer lines but all retrieval in general (also for O2 lines)*
- *Spectral shifts: Are fitted, this is a standard in atmospheric retrievals and doesn't result in errors as long as the lines are properly sampled (FWHM/SS) > Nyquist criterion).*
- *Radiometric: Again, the same hold for O2 lines. We indeed observe a potential 5*
- *Non-linearity: Can be an issue but will be even more so for stronger lines such as the O2 bands. Can be more easily calibrated out using Fraunhofer lines over barren surfaces and proper pre-flight calibration (extremely well tested for OCO-2, for example, as it would jeopardize CO2 retrievals).*

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- *Zero-level offset: We detected the offset in GOSAT data using Fs retrievals. It only happens in GOSAT band 1 and is unfortunate but can be avoided. We use an empirical correction, which works well. Affects the O2 band even stronger though (as more saturated than Fraunhofer lines).*
- *Doppler shifts: Fitted*
- *Solar activity: GOSAT records daily direct sun measurements. Can be used to evaluate this but so far we didn't observe any variability of solar lines in this region (as opposed to lines more in the UV/Vis).*

L2502 L19-22: Here you are absolutely falling into speculations! Retrieval of Fs from space is still considered by most people to be a great challenge, and here you are suggesting that photosynthesis could be quantified even under clouds! This statement bypasses and ignores all the work that is being done by many serious researchers in the world who are trying to find evidence for relationships between fluorescence and photosynthetic activity under cloudfree conditions and who are (in parallel to you) searching for suitable retrieval methods of Fs. And here comes your team, claiming to have all the answers?

We were somewhat surprised and taken aback by this statement. We didn't speculate but have shown using full radiative transfer simulations and retrievals that it is possible. Hence, it is a robust scientific finding and we can't understand the allegation of a speculation. If there is scientific literature stating the opposite, as you suggest, please refer to those. We have to mention that it is only possible when using Fraunhofer lines and not at all when using O2 lines in conjunction. Retrievals purely based on Fraunhofer lines were not possible at all until recently, so cannot be necessarily compared to previous results. We neither disregard nor discredit research done previously. Please be more specific when stating that we bypass and ignore all the work of others (i.e. cite peer-reviewed literature).

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L2505 L6: "(not oxygen, like FLEX)". Please remove biased suggestions like this one. If you want to help the chlorophyll fluorescence community or the FLEX mission with unsolicited advice, there are many ways to communicate in more direct ways, but I would not use a scientific paper for that purpose.

We will remove this statement. However, this was not at all a criticism but merely a statement. You can only see Fs through clouds if you use Fraunhofer lines only. FLEX was never supposed to measure Fs through clouds and we just wanted to clarify that our finding doesn't hold if you use O2 lines (as they are strongly impacted by clouds of course). Please refrain from derogatory language such as "unsolicited advice", it doesn't help either.

Interactive comment on Atmos. Meas. Tech. Discuss., 5, 2487, 2012.