

***Interactive comment on “Chlorophyll fluorescence remote sensing from space in scattering atmospheres: implications for its retrieval and interferences with atmospheric CO<sub>2</sub> retrievals” by C. Frankenberg et al.***

**Anonymous Referee #1**

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The manuscript "Chlorophyll fluorescence remote sensing from space in scattering atmospheres: implications for its retrieval and interferences with atmospheric CO<sub>2</sub> retrievals" from Frankenberg et al., submitted for publication in Atmos. Meas. Tech., covers several very interesting topics highly appropriate for Atmos. Meas. Tech. The manuscript is very well written and covers new and important aspects. I clearly recommend its publication after the authors have considered the (mostly minor) comments given below.

General:

Frankenberg et al. essentially address three different topics: (i) they present a first detailed error analysis for satellite XCO<sub>2</sub> retrievals related to spectral interferences with signatures resulting from chlorophyll fluorescence, (ii) they present study results and corresponding recommendations on chlorophyll fluorescence retrieval from satellites focussing on existing satellite data (GOSAT), and (iii) they give recommendations related to future satellites aiming at improving the precision of chlorophyll fluorescence retrievals.

Several interactive comments on this manuscript have been submitted. All of these comments have been answered by the authors except the very recent ones. All these comments and answers are related to items (ii) and (iii), i.e., to (dedicated) chlorophyll fluorescence retrieval. I am happy with the answers provided by Frankenberg et al. and appreciate that they have been provided prior to the end of the interactive discussion time period.

Many of the comments are focussing on findings related to the (possible future) satellite mission FLEX. FLEX aims at providing chlorophyll fluorescence retrieved from the 500-780 nm spectral region primarily by "exploitation of the O<sub>2</sub>-A and O<sub>2</sub>-B atmospheric absorption features" (Guanter et al., 2010) using moderate spectral resolution (threshold value: 0.3 nm Full Width at Half Maximum (FWHM); Guanter et al., 2010).

Based on the results shown in Frankenberg et al. and in previous peer-reviewed publications cited in that manuscript, Frankenberg et al. highlight the advantages of retrieving chlorophyll fluorescence from spectral regions containing clear (i.e., nearly absorption free) Fraunhofer lines in contrast to spectral regions containing strong telluric absorption lines (e.g., O<sub>2</sub>-A and/or O<sub>2</sub>-B bands). All the results presented by Frankenberg et al. are based on thorough simulations and analysis of real (GOSAT) data. I do not share the opinion that they are partially "speculation" as suggested by some of the interactive comments. Frankenberg et al. provide strong evidence that accurate

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and robust chlorophyll fluorescence retrievals using clear Fraunhofer lines is possible, that scattering (e.g., aerosol) related errors are small (essentially negligible), and that chlorophyll fluorescence retrieval based on clear Fraunhofer lines even permits accurate retrievals for significantly cloud contaminated ground pixel.

Frankenberg et al. underline that this is primarily due to the retrieval approach focussing on clear Fraunhofer lines only and that this would unlikely be the case for retrievals based on telluric absorption lines (e.g., O<sub>2</sub>-A and/or O<sub>2</sub>-B bands) due to the difficulty to disentangle scattering contributions from chlorophyll fluorescence contributions to the measured radiance (as discussed in detail in Frankenberg et al., GRL, 2011a).

A disadvantage of the "clear Fraunhofer line" method seems to be that it (i) requires quite high spectral resolution (Frankenberg et al. studied 0.05 nm FWHM, which is much higher than the FLEX threshold resolution (0.3 nm) and even higher than the FLEX goal resolution (0.1 nm); see Guanter et al., 2010), (ii) requires sufficient high signal to noise ratio (iii) and that this method is limited to certain spectral regions (e.g., to the 755 nm region used by Frankenberg et al.).

On the other hand I am not aware of any other peer-reviewed publication where it has been demonstrated that fluorescence retrievals with similar accuracy is possible for significantly different instrument specifications. According to my knowledge it has not been demonstrated that a similar performance for a FLEX-like instrument can be achieved (see Guanter et al., 2010, highlighting that several retrieval related aspects have not yet been fully addressed (e.g., thin or sub-pixel clouds) and that several critical parameters are assumed to be provided by Sentinel-3).

Frankenberg et al. point out that a disadvantage is the relatively poor chlorophyll fluorescence single measurement precision for existing instruments (GOSAT). They conclude based on simulations that this can be significantly improved for future satellite instruments by extending the spectral region. This is an important finding.

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For clarification they highlight that their concept based on clear Fraunhofer lines differs from the FLEX concept ("not oxygen, like FLEX") as FLEX primarily aims at exploiting the O2-A and O2-B spectral regions (see above) at quite low spectral resolution (for me it is not clear if the "clear Fraunhofer lines method" can be used for FLEX or due to the quite low spectral resolution of FLEX). I find that the remark "not oxygen, like FLEX" helpful to highlight the different concepts and to avoid misunderstandings. However, my conclusion from some of the interactive comments is that this is being interpreted as an attack to FLEX. This is not how I interpret this. Therefore I do not insist on removing that remark.

Especially in this context I carefully read the interactive comments and the answers from Frankenberg et al. I think that all aspects raised in the interactive comments have been carefully answered by Frankenberg et al. (except the most recent ones which have not yet been answered).

I assume that all issues raised by the various interactive comments will be considered by the authors when preparing the revised version of the manuscript (as indicated by Frankenberg et al. at various places in their replies). I will therefore focus on items not yet (fully) covered or clarified.

Concerning the interactive comments which have not (yet) been answered (e.g., the comment from Porcar-Castell) I strongly recommend to add a discussion on the potential limitations of retrieving chlorophyll fluorescence only from one small spectral region (e.g., around 755 nm) also covering aspects such as what chlorophyll fluorescence at 755 nm might tell us and what not (from the discussion I conclude that there are many open questions; in this context it would also be helpful to get an overview about what is not known but needs to be known to properly "interpret" the retrieved fluorescence signal); see interactive comment of Porcar-Castell on "F760" and the PS1 and PS2 related discussion also given in the contributions from Verhoef and Guanter.

Specific comments:

"Full-physics based retrievals": This is a term which has not been invented by the authors but is used, for example, to refer to NASA's OCO retrieval algorithm, which is referred to as "OCO full physics CO<sub>2</sub> retrieval algorithm" (see reference Crisp et al., 2010, as given in O'Dell et al., 2012, cited in Frankenberg et al.). I recommend to make clear that this term is not used to characterize the retrieval method used as one which considers everything but that this is an existing "name" with a particular meaning in a certain scientific community. I recommend to put it in quotes, e.g., "Full Physics" (FP) algorithm, when used / defined for the first time and subsequently refer to it as FP algorithm, for example. In any case I do not recommend to invent yet another name as suggested in one of the interactive comments.

Section 3, page 2491, lines 11-16: Although it is relatively clear, I recommend to highlight that for generating the simulated radiance observations, chlorophyll fluorescence is accurately modelled along with (multiple) scattering in the radiative transfer solver. At least this is my understanding. Is this correct? Scattering is only ignored within the retrieval scheme. The resulting error is however quantified as the simulated observations are modeled taking scattering into account. Therefore this is not a limitation. Is this correct? If yes all this might be explained more clearly in the manuscript.

Section 3.1, page 2492, line 1: Typo in "retrieved".

Section 3.2, page 2494, line 18: Please use also italic font for state vector element "s".

Section 4.1.2, page 2497, line 20: Please explain how "aerosol height" is defined in the simulation and for the retrieval (as used in Fig. 4).

Fig. 11: Annotation Fig. 11 (inlet): Remove "true" as the data points refer to "true" and "measured".

The following items are related to adding more explanations with respect to "true" and "retrieved" surface (TOC) and TOA fluorescence. They may be addressed individually or in combination:

Section 5.1, first paragraph, page 2501: Please add a more detailed explanation of Fig. 11. From the previous sections I understood that the retrieved parameter is the chlorophyll fluorescence at the surface (or TOC). This can only be identical with the TOA fluorescence if atmospheric transmission is 1.0 (i.e., no absorption, no scattering). Therefore please better explain why the "retrieved fluorescence signal ... accurately represents the true signal at TOA" ?

Related to this: My understanding is that the "true fluorescence signal at TOA" is given by Eq. (2) and is computed using the true surface (TOC) fluorescence. Is this correct ? My understanding is that the retrieved fluorescence is the one at the surface (or TOC). Please explain "retrieved fluorescence signal at TOA" ? Is it computed using Eq. (4) with  $F_{\text{surf}}$  on the right hand side being the retrieved (surface) fluorescence ?

Section 5.1, page 2502, and Fig. 12: Similar as previous item related to TOA and TOC fluorescence: Please explain how the discussed quantity used for the y-axis of Fig. 12 has been obtained. Please also explain the difference between the red and light red points.

Section 5.1, page 2503, and Figs. 13: Please explain how the TOA chlorophyll fluorescence has been obtained (see also previous items) ? Is it the TOC fluorescence multiplied with transmission obtained using AERONET AOD ? Or the other way around ? Apparently the latter as the figure caption suggests that the TOC fluorescence is obtained from the TOA fluorescence. This appears to be in contraction to the previous descriptions stating that the retrieved fluorescence is the one at TOC, not at TOA. Please clarify.

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

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