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Atmospheric Measurement Techniques Discussions

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Interactive Comment

Interactive comment on "Global monitoring of terrestrial chlorophyll fluorescence from moderate spectral resolution near-infrared satellite measurements: methodology, simulations, and application to GOME-2" *by* J. Joiner et al.

J. Joiner et al.

joanna.joiner@nasa.gov

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We thank Referee #1 for a thoughtful and thorough review and suggestions to improve the paper. We respond to specific comments (repeated here for clarity) in bold below.

P3885/L6: The only way to contribute to the carbon cycle using fluorescence is via GPP. Please rewrite: "as well as assessment of the terrestrial carbon budget by providing more accurate estimates of gross primary productivity (GPP)"

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Thank you. We have made the change as suggested.

P3885/L11: Photosynthesis is GPP and can be (in a simplifed way) approximated by two components: light absorption (APAR) and the utilization of it (LUE). FS is known to be strongly related to its excitation energy (APAR) and was found to be sensitive to changes of photosynthetic activity (LUE). Please rewrite: “fluorescence is correlated to the amount of absorbed photosynthetic active radiation (APAR) and the efficiency of the plants to utilize this light to drive photosynthesis (LUE).”

Thank you. We have made the change as suggested.

P3885/L13-...: Please clarify your argumentation by specifying why FS is complementary to reflectance based vegetation indices? You might use these aspects in your argumentation: - Greenness bases indices are linked to the chlorophyll content and indicate potential photosynthesis, but FS is supposed to be an indicator for actual photosynthesis - PRI is sensitive to the de-epoxidation state of xanthophyll pigments within the xanthophyll cycle, a protection mechanism evolved in parallel to FS to dissipate excessive energy.

Thank you. We have made the additions as suggested.

P3887/L18-20: You mention that the proposed approach does not require nearby non-fluorescing targets. But, as far as I understand, you need observations on a daily basis to do the principal component analysis. Please update the statement made in the introduction accordingly.

We removed the previous statement and added the following statement to the next paragraph: “While our approach does not require a nearby non-fluorescing target as in other techniques, a representative sample of observations over non-fluorescing scenes is needed in order to generate a comprehensive set of PCs. For this purpose, we use cloudy observations over ocean covering a large range of latitudes on a daily basis.”

P3887/L21-22: Please rewrite: “Our methodology is similar to approaches developed for ground-based instrumentation (Guanter et al. 2013) in that: : :”

Thank you. We have made the change as suggested.

P3888/L10-15: I would recommend replacing the summary with some statements highlighting the implications of your work for the research community.

We replaced the summary with a some statements as suggested: “More accurate and frequent measurements from GOME-2 will lead to a fluorescence dataset with unprecedented temporal and spatial resolution; this in turn should enable detailed studies including more direct comparisons with flux tower measurements.”

P3888/L17-24: I am wondering if the discussion of SCIAMACHY is relevant here – you might consider moving it to the discussion section.

Agreed. We move this discussion to the conclusions and expanded it by adding that the original GOME and SCIAMACHY can extend the fluorescence satellite record back in time to 1995.

P3889sqq: Why do you introduce new abbreviations for FS (IF) and extraterrestrial solar irradiance (F) rather than using the ones more or less established in RS and used in your previous work?

This choice was made after some consideration. Firstly, F is typically used in the atmospheric community to denote the solar flux or irradiance, so that can be confusing in a journal such as AMTD. Secondly, we wanted to highlight that we are actually measuring a radiance, not a flux, and I is typically used for radiance. However, since this notation seems not to be catching on, we have changed back to the more standard F_s for fluorescence and use E for solar irradiance as in previous work. We changed the notation for retrieval error covariance to S_r.

P3890/L18-P3890/L5: I would recommend moving this paragraph in front of P3890/L1.

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Currently, it is difficult to understand why you are doing all these mathematical reformulations.

We agree that this part could be better organized. We moved the first sentence of this paragraph as recommended, but left the rest where it was as it relates to Eq. 2 that should come before this discussion.

P3892/L1: It was unclear for me – until the next page – how you could simulate at sensor radiance without having a vegetation model. You could consider rewriting the first sentence: "To quantify retrieval errors, we conduct detailed simulations using combined atmospheric and vegetation models over a wide range of conditions."

Thank you. We made the recommended revision.

P3893/L25: Radiative transfer in the O2-A band is indeed complex and the reasons are comprehensively listed. You are proposing a retrieval scheme which also exploits the H2O band around 720nm. A similar listing and discussion on disturbing factors is required.

Thank you. We added a sentence stating that "absorption by water vapor in the 710–745 nm spectral region also depends upon these parameters and is similarly complex; though less affected by saturated lines, the profile is of course more variable."

P3895/L27-P3896/L8: Please briefly indicate why the PCA's differ for the simulated and the real data.

We added "The PCs for simulated and real data are expected to be different as PCs from the real data may contain information related to instrumental artifacts and processes not included in the simulated data (e.g., rotational-Raman scattering)."

P3897/L11: Please extend the description of your method. How exactly and where do you select data to run the PCA? What are required characteristics of these data used

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as input for the PCA?

We extended the description of the method. We added a flow diagram and explanation that describes the data used in the PCA. Please see also the response to Dr. Stammes.

P3897/L22: Please specify the limits you tested for cloud contamination.

The limits (0-50%) are now listed.

P3902/L15: Are the negative values an effect of data noise, or a result of one of the assumptions made, or caused by less representative data used to calculate the PCA's? Please give a short indication.

We added "The slight biases (both positive and negative) in these areas are likely not related to instrumental noise as this would be removed in a long-term average. There are several potential sources of these small biases including simplifying assumptions in the forward model, small correlations between the fluorescence spectral signal and that of reflectivity and/or some of the PCs, lack of representativeness of the PCs used in the retrieval, and systematic instrumental artifacts."

P3903/L3: Why do you not sample FS at the same wavelength as the GOSAT FS retrieval (755nm) does? This would make the comparison much easier.

We have now referenced the GOME-2 F_s data to the same wavelengths as GOSAT as explained in the revised text. New figures are provided. The text has been adjusted accordingly.

Please include or extend a discussion on the following aspects: - Problems related to the retrieval of FS in highly variable H2O absorption bands. Does it complicate the retrieval or is the complexity comparable to retrieval in O2 bands?

Please see response to above comment, repeated here. We added "Absorption

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by water vapor in the 710–745 nm spectral region also depends upon these parameters and is similarly complex; though less affected by saturated lines, the profile is of course more variable."

- Impact of the distribution and sampling frequency of data used to calculate the PCA on the retrieval accuracy. Can it be that the selected spectra do not cover the variability introduced by the SAA, leading to higher uncertainties in South America?

We added "The distribution and sampling frequency of the data used to generate the PCs leads to higher retrieval uncertainties in the SAA; the relatively small number of PCs used in the retrieval generally does not capture the highly variable errors found in the region."

- Validation of results. Right now the validation only relies on a visual comparison of GOSAT and GOME-2 FS retrievals – which is fine as these results are published and its plausibility was evaluated using various approaches. However, the papers describing the GOSAT retrieval (Joiner et al. 2011, Frankenberg et al. 2011, Guanter et al. 2012) indicate that, because of the coarse spatial resolution, validation is impeded for these data and only indirect strategies can be applied (e.g., using simulated data, methodology checks, plausibility checks). A validation of the satellite based FS (aggregated over many kilometers) is still challenging and would require alternatives which have to be developed (e.g., scaling approaches using field, airborne, small footprint satellites, etc.). Please include a short discussion on validation problems.

We added "While the GOME-2/GOSAT comparison may be considered as a consistency check and the simulation experiments provide evidence that the retrieval approach is valid, there are short-comings to these types of evaluations. Firstly, the GOSAT retrievals themselves have only been evaluated using indirect strategies such as plausibility checks and simulation experiments. Secondly, the simulation studies, while quite detailed, generally do not contain all the complexities found in real satellite data (e.g., instrumental artifacts and RRS). A more

direct validation using ground- and aircraft-based data remains challenging owing to the large pixel sizes of the current satellite instruments. Approaches need to be developed and tested to scale up measurements made on small scales (ground-, aircraft-, and small-footprint satellite data) to the larger GOME-2 pixels."

- Your retrieval relies on some assumptions, including: i) atmospheric scattering is small and was not considered (P3890/L1; ii) the radiative transfer equations are only valid for monochromatic light (P3890/L17); iii) distinct spectral structures of e.g., FS were assumed (P3891/L6); no rotational Raman scattering modeled (P3892/L22); iv) no consideration of directional effects (P3892/L26). Please discuss potential impacts on the retrieval accuracy.

We added a subsection at the end of the Sect. 4 discussing points i-iii above. "As noted above, our retrieval approach relies on several simplifying assumptions. For example, we assume that atmospheric scattering small, that the radiative transfer assumptions are only valid for monochromatic light, and that the spectral structures of F_s and ρ_s could be modeled with a few parameters. The simulated data contain none of these assumptions; the radiances are generated monochromatically with scattering before they are convolved with the instrument response function, and the spectral dependences of F_s and ρ_s are based on model and spectral libraries. Therefore, our simulation results should accurately reflect errors produced by these assumptions. As can be seen, the biases and errors produced by these simplifications are relatively small. We did not simulate RRS in the simulation. Our assumption in processing GOME-2 data is that the PCA will be able to disentangle the spectral effects of RRS from those of F_s. This will be discussed further below."

We added some discussion regarding iv-v in section 5. We did a bit of rearranging in Sect. 5.2 and added "The filtering uses data only for SZA$< 70°$, where RRS effects should be small. We see no obvious biases resulting from RRS for

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these conditions." We also added "We have observed systematic variability with respect to view zenith angle for a given area over the course of a month as has been reported previously for GOSAT and SCIAMACHY data..." (with references) and mention that this will be explored in future works.

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